U.C. \$ 2.00 MN . 50

COO-818-96

AUG 10 1966

Technical Report

MASTER

for

Research Program in Neutrino Physics, Cosmic Rays and

Elementary Particles

Contract AT(11-1)-818

1 October 1965 to 30 September 1966

RELEASED FOR ANNOUNCEMENT

IN NUCLEAR SCIENCE ABSTRACTS

F. Reines

F. Reines, Principal Investigator,
Professor of Physics and Department
Head

Case Institute of Technology
University Circle
Cleveland 6, Ohio

July, 1966

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

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.

Atomic Energy Commission Contract AT(11-1)-818

Research Program

in

Neutrino Physics, Cosmic Rays and Elementary Particles

by

Frederick Reines
Marshall F. Crouch
Glenn M. Frye, Jr.
Thomas L. Jenkins
Robert M. Woods, Jr.
William R. Kropp
Henry S. Gurr

Professor of Physics
Professor of Physics
Professor of Physics
Associate Professor of Physics
Assistant Professor of Physics
Research Associate
Research Associate

Part I. Progress Report - Technical

I. Status of Program on Neutrino Physics

A modified version of the "table top" study of $\bar{\nu}_e + p$ which may not require detection of the delayed coincidence between product positron and neutron is now under investigation. If successful a measurement of significantly greater accuracy will result since only the positron is involved and hence the uncertainties in the neutron detection efficiency will be eliminated. A paper is in preparation on our observation of the reaction $\bar{\nu}_e + d$. Equipment is being readied for a second improved approach to the detection of double beta decay of Nd^{150} .

The large (360 Kgm) composite NaI-plastic detector for the detection of the elastic scattering reaction ($\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$) is now complete. Some preliminary measurements have been made of its characteristics and development of the associated electronics continues.

The equipment for the two solar neutrino experiments ($\nu_e + d$ and $\nu_e + \text{Li}^7$) in the Morton Salt Company mine is now largely in hand. Some preliminary tests have been made of the Cerenkov D_2O system. A slight modification of the D_2O system promises to give a new test of baryon conservation which makes fewer assumptions than previous experiments.

The latest and most ambitious test to date of the principle of baryon conservation has been completed. Assuming modes of decay which violate only baryon and lepton conservation the lifetime is $> 2 \times 10^{28}$ or 8×10^{29}

years, depending on the specific mode. This represents an improvement in the limit by an order of magnitude. The work was done using the South African neutrino detector and is being prepared for publication.

The South African experiment has continued to produce data on neutrinos and cosmic rays deep underground. A directional Cerenkov detector section has been installed to distinguish neutrinos which penetrate the earth from below. A solar neutrino detector designed to detect the sun via the elastic scattering reaction is installed and under preliminary test.

A new laboratory is being prepared in the same deep mine which houses our present temporary quarters.

II. Neutrino Physics Using Reaction $\bar{\nu}_e +$

Elastic Scattering, $\bar{\nu}_e + e^-$

The complex composite NaI-plastic detector has now been completed by the Harshaw Chemical Company and delivered to us. Studies of its response to cosmic rays and various gamma ray sources are encouraging and we are continuing our development of the ancillary electronics for pulse shape discrimination and the trigger and display logic. An insert shell has been built and shipped to the Savannah River Plant for incorporation into the present large liquid scintillation detector which will then be used for the NaI-plastic system (see COO-818-77 and preceeding annual reports for more background information).

This unusual (360 Kgm) NaI-plastic detector is shown in Figures 1 and 2. Figure 1 shows the assembled detector. Figure 2 is an end view of the system without the photomultiplier tubes in place. Note the optical clarity of the scintillator. The photomultiplier tubes and light pipes are so arranged that the signals label the element, NaI or plastic, in which the scintillation occurs.

This detector is the result of work carried out under the neutrino program at Case Institute over a period of seven years. It took about two years for Harshaw to build it. We look forward this next year to a full laboratory test of the system and eventually its transport to SRP where further background studies and the $\bar{\nu}_e + e^-$ measurements will commence. The laboratory test will be designed to measure the background reduction the detector can provide and hence is eagerly anticipated.

Figure 1

Assembled NaI - Plastic Detector

Figure 2

End view of NaI - Plastic Detector
before mounting of photomultiplier tubes

Improved "Table Top" Experiment, $\bar{\nu}_e + p$

Measurements are underway at the Savannah River Plant to detect the reaction $\bar{\nu}_e + p \rightarrow e^+ + n$ by means of the positron only. The advantage of such an approach is that the overall efficiency is higher (the neutron detection efficiency in the table top array was 40%) and is better determined. Furthermore, once released from the "bondage of the neutron", reactions could be studied in which no neutron is produced, e.g. $\bar{\nu}_e + \text{He}^3 \rightarrow \text{H}^3 + e^+$, so enlarging the field. These studies indicate that the primary source of background is due to neutrons escaping from the reactor and neutrons produced by muon capture in the vicinity of the detector. Thus far a signal to background ratio of $\sim 1/20$ has been achieved but there seems to be no reason why this cannot be significantly improved by appropriate neutron shielding and a cosmic ray anticoincidence arrangement.

$\bar{\nu}_e + p$ with Large Liquid Scintillator

Nearly all the necessary data for measurement of this reaction using the large scintillator tank located at the Savannah River Plant have been acquired. The data are being reduced.

Neutral Lepton Current

This experiment was postponed in view of the interesting results obtained in the first "table top" approach and the difficulty encountered in reducing background so as to be able to detect a sufficiently small cross-section. There is as yet no experimental data which excludes a cross-section larger than 10^{-40} cm^2 but the theoretical guess is that if the neutral lepton current interaction exists, it is not much different

in strength from the other reaction cross-sections for fission $\bar{\nu}_e$ ($\sim 10^{-44}$ cm²). This suggests we would only be reaching for a null result at the present level of sensitivity. Since the problem is primarily one of background reduction it is hoped that the work on the improved table top will give information which is useful in this direction.

In thinking about this matter of a neutral lepton current it became apparent that data obtained many years ago by the Los Alamos group in connection with the early $\bar{\nu}_e + p$ studies can be interpreted to set an experimental upper limit for one possible inelastic reaction which could be produced by a neutral current, i.e. $\bar{\nu}_e + d \rightarrow \bar{\nu}_e + p + n$. Information obtained as a by-product of the Case deuteron experiment ($\bar{\nu}_e + d$) can also be used for this purpose. The reaction would in this instance be signaled by capture of the product neutron. A conservative analysis of the data indicates that the cross-section for deuteron disintegration by fission antineutrinos is $< 10^{-40}$ cm².

All necessary data for measuring this reaction cross-section have been acquired and are in the process of being reduced. It appears that a sufficient number of events have been obtained to provide a result with a statistical error of about $\pm 30\%$ for the integral of cross section times flux over the energy range of interest. It should be possible to obtain a crude energy spectrum of the events. A paper is in preparation.

III. Solar Neutrino Experiments:

D₂O Experiment

The apparatus for the detection of solar neutrinos via the reaction $\nu_e + D \rightarrow 2p + e^-$ has been assembled in the mine of the Morton Salt Company at Fairport Harbor. Initial operation of the equipment showed an apparent large background. Subsequent tests have indicated that the source of this spurious signal may be instrumental in nature although, its exact cause has not yet been determined. Further study is in progress. A description of the experiment may be found in COO-818-77.

Li⁷ Experiment

This experiment is designed to detect solar neutrinos through the observation of the electrons produced by inverse beta decay in ${}^7_3\text{Li}$. The target consists of 1600 pounds of natural lithium in the form of eighteen 1 inch thick slab assemblies separated by 2 inches of mineral oil based liquid scintillator. The assembly is viewed by an array of 100 photo-multiplier tubes and is surrounded by an anticoincidence blanket. The experiment is being assembled in Case's laboratory 1950 feet underground in the Fairport Harbor Mine of the Morton Salt Company.

The Morton Company has completed the necessary site modifications, which included digging a large pit to provide access under the detector, and installing a new 40 KVA power line. This was very graciously done at no cost to Case.

The detector tank (6' x 12' x 5' high) and its supporting structure have been lowered to the site and assembled. A wall has been constructed across the end of the laboratory area to provide a darkened area for the

detector. A monorail and hoist have been installed for handling the lithium assemblies. The electronics house has been rebuilt for the new configuration.

All of the liquid scintillator has been lowered to the site. The 148 lithium metal slabs have been fabricated and are on hand at Case. All of the inner parts of the detector have been fabricated and are on hand, as are all 120 photomultiplier tubes.

It remains to clean and check carefully the several inner parts for the detector, transport them to the mine and assemble the detector.

The difficult problem of enclosing the lithium assemblies in liquid tight, optically clear packages has, hopefully, been solved. Thin Mylar was finally abandoned because of pinhole leaks and optical absorption and then (30 - 60 mil) ultra violet transmitting Plexiglass tried. Preliminary tests on a full scale mockup of one detector section indicate the Plexiglass will be satisfactory. The large task of cleaning the lithium, fabricating the assemblies and the enclosures and transporting the 18 completed units to the mine is yet to be done.

The electronics is about 80% complete. Most of the components have been purchased. The various amplifier and mixer boxes for the display system are in the final stages of assembly and testing. The data recording scopes and cameras are on hand. It still remains to fabricate the delay line assemblies, construct the triggering system, design and construct the master control circuits and test the total system.

The large amount of work remaining consists mainly of transporting, assembling, and fitting.

It is hoped that by late summer or early fall of 1966 it will be

possible to install a few photomultiplier tubes, pump in some of the scintillator, and begin studies of the system, the detector response and the background. It should then be possible to begin inserting the lithium assemblies by January 1967. It is expected that at least two years of data collection on the full detector will be required.

IV. Baryon Conservation

$D \rightarrow n + ?$

The same apparatus used in the D_2O solar neutrino experiment is being modified to test the law of baryon conservation in a manner which is virtually independent of the assumed decay mode of the baryon. This experiment, mentioned in the previous proposal (C00-818-77), involves a search for the spontaneous creation of free neutrons in the large tank of D_2O , i.e. a search for the neutron created in $D \rightarrow n + ?$. The neutron detector simply consists of a liquid scintillator tank placed adjacent to the D_2O and containing iron plates. This detector will utilize the radiative neutron capture in iron (to produce a 7 MeV gamma) as the detection mechanism. All the equipment is on hand and measurements are scheduled to begin during the summer of 1966.

Assuming all laws valid but lepton conservation

This experiment was performed using the South African equipment and interpreting the data in terms of a lower limit on the stability of nucleons against decay into lighter fragments. It tests the assumption that nucleon decay does not occur when all other conservation laws are valid, except that of lepton conservation. Depending on the assumed decay mode within this class of decays a lower limit on the half life of the nucleon from 2×10^{28} to 8×10^{29} years is established. These numbers are to be compared with the best previous numbers of 5×10^{27} to 4×10^{28} years.

The experimental arrangement is that of a detector in an underground cavity. The nucleons whose decay is sought are in the detector itself

and within the cavity walls. An important simplification in the interpretation of the experiment is provided by the fact that the response of a detector in a cavity with thick homogeneous walls is independent of the shape or size of the cavity.

It is apparent that a significant improvement in our test of baryon conservation is not easily achieved as it was in the past but would represent a major experimental effort.

V. Double Beta Decay

Our initial experiment with Nd^{150} has set a half life limit of $>3 \times 10^{17}$ years for the two-neutrino mode.¹ The final results of this experiment are in press.

The apparatus for improving the half life limits, described in the previous proposal,² is in the final stages of assembly. Initial operation, for the purposes of determining background, is expected in the late summer of 1966.

VI. The South African Deep Mine Neutrino Experiments

General

The experiment to study high-energy neutrinos in the cosmic radiation has now been operating almost two years in the East Rand Proprietary Mines near Johannesburg, South Africa. For nearly a year the expanded array has been accumulating data virtually without interruption at level 76 of the E.R.P.M. Hercules Shaft, at a depth of 10,492 feet. The Case-Wits research group has enjoyed fine relations with the mine authorities so that good progress has been made as well in installation of the large cylindrical detector with which it is hoped to observe solar neutrino events and in construction of the new deeper laboratory space at level 77. Cerenkov directional detectors were installed and have been in operation for the past several months, during which the operating personnel have been able to devote a considerable part of their time to introducing refinements in the system such as the automatic light pulser monitor and the geophone coincidence detector, as well as improving the procedures for systematic analysis of the recorded data.

The measured neutrino rate $21 \pm 5/\text{yr}$ for the system enables us to set limits on the inelastic cross-section $>15 \text{ BeV}$ (i.e. above the accelerator range) as well as a lower limit on the mass m_w of the intermediate boson of $m_w/m_p > 3$. A comparison of the measured rate (21/yr) and a conservative estimate of the expected neutrino rate (15/yr) suggests that the inelastic cross-section does not rise even as rapidly as linearly in the energy range >10 to $\sim 100 \text{ BeV}$. This interesting indication for neutrino interactions in the energy range beyond the reach of accelerators is being studied further.

Experimental Arrangement

The recorded data continues to confirm that, while the very deep site employed is still not sufficiently well-shielded to reduce the flux of charged cosmic ray particles through the apparatus to negligible proportions, the so-called "rail geometry" coincidence array of detectors gives an effective depth which is essentially infinite. From Figure 3 it can be seen that this array is sensitive to penetrating particles with generally horizontal trajectories, so that the charged cosmic ray particles which are sharply peaked in the vertical direction cannot give cross-tunnel coincidence signals, though information on the flux of these more nearly vertical particles can be obtained from single tank events. Thus as suggested in Figure 3 the East-West double coincidence requirement, which actually represents an eight-fold coincidence signature involving the four photomultiplier tubes at the four corners of one scintillation tank on each side of the tunnel, means that the events recorded are almost certainly muons from interactions of cosmic ray neutrinos with nuclei in the nearby rock. At the present time (1 July) 17 such events have been recorded. The improved chronotron system has been in operation since November 1965, together with a new automatic monitoring arrangement which sequentially records the signals from pulsed light sources mounted on each tank at regular intervals. In addition a geophone coincidence detector has been placed in operation to reveal any possible correlations between the various recorded events and earth movements due to blasting or post-blasting relaxation of the surrounding rock.

NEUTRINO-DETECTION ARRAY currently in use at the authors' South African site is made up of 36 separate detector elements. Each element is called a scintillation counter and consists of an 18-foot-long Lucite box filled with scintillating liquid—mostly medicinal mineral oil—at each end

of which are two photomultiplier tubes. When a charged particle (in this case a muon) traverses the liquid, it loses energy, some of which appears as a flash of light (*color*). The photomultiplier tubes convert the light into an electrical pulse, which is then analyzed. In order to distinguish between muons traveling horizontally and those traveling vertically, the detectors are arranged in two parallel horizontal rows, with the broad faces of the boxes side-

ways. The detectors are stacked three high in order to measure three different angular ranges. Two muons are shown being detected. Entering from the left and passing through a detector in each row is a daughter muon produced by the interaction of an atmospheric muon-type neutrino with the surrounding rock. Entering from the top and passing through just one detector is a sister muon produced by a cosmic-ray interaction in the atmosphere.

Figure 3

(This figure plus caption is from an article by Reines and Sellschop which appeared in the Scientific American, February, 1966).

The Cerenkov Detectors

The array of 16 Cerenkov direction-sensing detectors has been operating since the end of 1965, using spare chronotron circuits for recording their signals. Three events have been recorded in this part of the system, of which two were clear cases of downward travelling particles. For the third event the Cerenkov detector indicated an upward travelling particle, but unfortunately the signals from the scintillation detectors showed a complexity indicating that the event probably involved more than a single particle, so that a clear-cut physical interpretation is difficult to make. However, continued operation of this small sub-array will certainly yield some interesting events in the remaining period of operation at the present site.

Solar Neutrino Interactions

Efforts to lower the threshold energy of the array resulted in several months of operation during which time the system was in principle sensitive to elastic scattering interactions produced by solar neutrinos. Although it is still believed possible that very careful analysis of the data may show the presence of these signals, it is difficult to observe them because of the background of signals from pairs of unrelated gamma rays striking the array simultaneously. Therefore another detector featuring a more favorable volume-to-surface ratio has been installed to look for solar neutrino interactions. This detector, called SASNES (South African Solar Neutrino via Elastic Scattering detector), is a cylindrical pot partitioned into five compartments to combat pileup effects and aggregating about 1000 gallons of liquid scintillator. The detector

proper has already been installed, together with most of its 2.4 foot thick shield of paraffin wax and boric acid. New amplifier, logic, and recording circuitry has been developed to permit operation with a ten-fold improvement in time resolution over the previous system. Construction of these circuits is now nearing completion. Considerable testing of the detector has already been carried out, verifying that the arrangement of interleaved photomultiplier tubes on the various compartments does indeed reduce the variation of signal amplitude with event location to about 10%. The expected signal rate with this detector is about 20 events per year for recoil electrons > 6 MeV.

Cosmic Ray Measurements

Although no cosmic rays have ever been observed at depths as great as the present experiment in any other measurements, more than 30 vertical coincidence events and over 100 single tank events due to the penetrating component of the cosmic radiation have been observed at level 76. Upon proper calculation of effective area and solid angles for the array it will be possible to give quite a good figure for the cosmic ray flux at this depth.

Conversi Tube Array

Plans for the high spatial resolution visual detector array are well-advanced. The existing array of 60 scintillation detectors is to be rearranged in the new laboratory now under construction at level 77 so as to give a single sided formation of 20 bays. The surface of these detectors is to be covered with 58,320 neon flash (Conversi) tubes in

12 layers, half oriented horizontally and half vertical. The layers will be arranged so that the spacing may be varied to give any angular resolution desired up to a maximum of $\sim 1/2$ degree. The system will be made up of elements which are metal boxes approximately 2' x 6' which house and provide the electrode structure for two layers of tubes. A cluster of 18 of these elements, called a module, is an electrical unit which serves 1/3 bay. A grouping of 6 elements, called a sub-module, is a mechanical unit which rolls on overhead tracks to permit variation of the spacing of the system as well as maintenance of the detector assemblies.

The scintillation detector signals will be used to locate the bay in which events of interest occur, and to subsequently activate the Conversi tubes for that bay and the two neighboring ones. This should cover essentially all the interesting events since in nearly 2 years of operation we have never seen a signal in more than two adjacent bays. The pattern of Conversi tubes which are lighted in each event will be sensed by cadmium selenide cells with associated SCR circuits and displayed on a board of incandescent lamps arranged to map the horizontal and vertical pattern without distortion. This lamp board will contain 972 lamps, sufficient to display a single module, and the signals from the nine modules interrogated following each event will be displayed in sequence and recorded on video tape to permit rapid retrieval of the stored information. It is possible that a permanent film record will also be made.

The principal uncertainty in the planned system is the question of whether the light sensor circuits, which work well in small-scale tests, will be able to function under the severe conditions of electrical pickup which may be present when high voltage pulses are applied to large numbers

of elements. This will be investigated as soon as possible, and wherever possible all component designs are being made compatible with conventional direct recording by camera or videcon of the light flashes from the tubes.

This approach represents a great simplification without loss of information over the spark chambers previously envisaged. It should speed the time scale and be less expensive. Procurement of the components for the display panel and flash tubes plus auxiliaries for the first three bays is well under way.

New Laboratory on 77 Level

The excavation for the new laboratory on level 77 (10,600 ft. below surface) in the Hercules shaft of the East Rand Proprietary Mines is proceeding satisfactorily. As of this writing (1 July) the entry tunnel and electronics area have been rough hewn. The scheduled completion date of the 750 ft. long laboratory consisting of entry way plus electronics and detector areas is early next year. This new laboratory will be available for an indefinitely long period because, unlike the present laboratory, it is away from the gold bearing reef. The mine has kindly agreed to let us remain in our present location beyond the original September 1966 date so that we will move with minimum interruption to our experiment to our new location.

Personnel

There have been no changes during the period under review in the group of permanent staff members at Case who direct the operation of the experiment and plan its future course except that Professor T. L. Jenkins has devoted most of his efforts to other aspects of the program and Staff Physicist

Bruce M. Shoffner resigned his post at Case in July, 1966. The field party from Case consists of Dr. William R. Kropp, Henry S. Gurr, Henry W. Sobel, and John Lathrop. Professor J. P. F. Sellschop, Head of the Nuclear Physics Research Unit, and graduate student Basil Meyer continue to constitute the staff group from the University of the Witwatersrand involved with the scientific aspects of the experiment. Electronics technician John Baird has replaced Richard Atkinson, and Greville Nelson, who has done an excellent job of film scanning, has been joined by Myra Stein in order to handle the increased volume of recorded data. Members of the Case staff have continued to make periodic visits for equipment installation and for discussions of various current problems associated with the experiment as well as plans for the continuing development of the experiment based on studies of the data already accumulated.

Movement of Personnel

This past year the following Case people travelled to South Africa in connection with the experiment:

Research Engineering Associate A. A. Hruschka - Jan. - Mar. 1966

Professor F. Reines - October 1965, March 1966

Dr. W. Kropp returns to the U.S.A. this July for a month's consultation and research at Case after which he will return to South Africa.

Professor J. P. F. Sellschop of Wits visited Case in June while in the U.S.A. in another connection.

Mr. Henry Gurr is scheduled to return to the U.S.A. sometime in September.

VI. High Energy Physics Using Accelerators

The activities in this area were centered on building up the group which now numbers four men of faculty rank and three graduate students at Case Institute. In addition the space modifications have been largely accomplished and the group moved in.

The construction of a computer controlled flying spot scanner for which funds were provided during the year under report has proceeded to the point where major components have been purchased. A program of kaon physics using spark chambers is now envisaged and is described in the renewal proposal.

The machine will be a flying spot scanner for automatically scanning and measuring spark chamber film. The scanner will operate under the control of an IBM 1800 computer which is being purchased from the NSF institutional grant. The design of the machine is unique in that it will scan a single line at a time across the film image and detect and measure the position of the first opaque spot that it encounters in the sweep. The design precision of the machine is one part in 1000. Each scan will be separately programmed as to initial position and direction by the computer and the coordinates for each scan will depend on the results of previous scans. This approach represents a sort of hybrid of the point by point search method of the SPASS system at M.I.T. and the complete raster scan performed, for example, by the "Baker Wheel" machine at BNL. It will be capable of a point by point search also. It is intended that this machine be operating by late spring of 1967, at which time it will be used for analysis of film being generated in an experiment in which one of the Case group is now involved.

Meetings and Conferences

Papers were given by various members of the group at:

- A) The International Conference on Weak Interactions held at Argonne National Laboratory on October 25, 1965.
- B) The Cosmic Ray Conference (I.U.P.A.P.) in London, England, November, 1965.
- C) The Tenth Scintillation & Semiconductor Counter Symposium sponsored by IEEE Nuclear Science Group, AEC, on March 2-4, 1966, in Washington.
- D) The American Physical Society Meeting held in Washington, D. C. in April, 1966.
- E) A small meeting was held in Johannesburg (October 12, 1965) to discuss the problem associated with constructing a very deep underground laboratory.

Student Training

In addition to the ten graduate students working for advanced degrees, twenty-one undergraduates and one graduate student were employed at one time or another during the year as laboratory assistants.

Facilities

The space in the Wickenden Building on the Case Campus has been remodeled and is now occupied by the high energy group.

A major reconstruction of our laboratory in the Morton Salt Company mine has been accomplished in order to accommodate our local underground program.

Guests

For the past year we have been hosts in the Case salt mine laboratory

to an experimental group working on double beta decay and headed by Professor C. S. Wu of Columbia University.

VII. Cosmic Ray Balloon Program

The Balloon program at Case has been supported by the AEC since its inception in late 1960. This support has enabled us to study several aspects of the cosmic radiation at high altitude, first with nuclear emulsions and then with spark chambers. This latter technique has proved especially powerful and there is every reason to believe that it will be extended to satellites in the near future. We have been receiving supplementary funding from the NASA Manned Spacecraft Center in Houston for the development of a satellite spark chamber since May, 1965, and the prospects are favorable for its continuation through FY '67. Therefore no additional request is being made from the AEC for the balloon program and this report plus reprints of papers under preparation or resulting from the period of AEC support represents a terminal statement for this area of Case Contract AT(11-1)-818.

Gamma-Ray Flights

Our major effort during this period has gone into designing a large spark chamber system primarily for the gamma-ray experiment, but one that will be adaptable to other chambers. For gamma-rays it has a sensitivity an order of magnitude greater than our original system and near the equator at an altitude of 2 mb it should be able to detect a point source of gamma-rays $\gtrsim 10^{-5} \text{ cm}^{-2} \text{ sec}^{-1}$. Because of the intense interest in quasars we organized an expedition to Panama in October '65 specifically to look at 3C 273, the nearest quasi-stellar radio source. The expedition was made possible by the scientific encouragement of Professor Edward Teller

and the financial support of the AEC. Unfortunately a combination of factors resulted in our gondola being lost on the first flight. We have received no further information about it even though it is believed to have come down over the land. Since then we have been building two gondolas in order to have a spare for future operations.

We have two more series of gamma ray flights planned for the present year. As of this writing (July, 1966) we are in Palestine, Texas from which location we will make two or three flights to complement our previous results at this latitude and flight test the new system. In September we will return to Panama to complete the quasar flights.

The final results for our flights 30-P and 31-P from Texas in February 1964 are included in Table I. The limits to the gamma-ray flux are the lowest that have been set experimentally.

We did notice one region at 83.3° right ascension and $+39^\circ$ declination which had an unusually high density of pairs in a plot of pair density vs. celestial coordinates. Estimates of this being a chance fluctuation lie in the range 8 - 16%. We make no claim for this being a source but this region must be scanned again on future flights. These results have been submitted to Phys. Rev. Letters and when the calculations on 101-P and 105-P are finished and the energy analysis complete, they will all be included in a final article.

Electrons

The gas Cerenkov counter for this experiment has been completed and tested.

Additional tests have been made on plates covered with a dielectric

Table I

Upper limits at the 95% confidence level to the gamma-ray flux, $30 < E_\gamma < 500$ MeV, from ten possible sources. The number of background pairs, N_b , is the average number of pairs in that direction.

Possible Source	Number of Pairs Observed in a 3° cone, N_p	Number of Background Pairs, N_b	Upper Limit to Gamma-Ray Flux
Crab Nebula	8	3.0	$1.9 \cdot 10^{-4} \gamma's \text{ cm}^{-2} \text{ sec}^{-1}$
3C 138	1	2.5	0.5
3C 147	1	2.8	0.4
3C 181	5	3.0	1.2
3C 186	2	4.0	0.3
3C 191	3	2.5	1.1
3C 196	4	3.2	1.0
3C 208	4	2.5	1.3
Cyg A	1	1.1	1.8
XR-1	1	1.1	1.8

to improve the multiple sparking efficiency. It has been found that glass sprayed with a thin layer of carbon is particularly promising.

Accelerator tests and balloon flights are scheduled for early 1967.

Neutrons

This system has been designed and is under construction. It will detect neutrons in the range 12 - 100 MeV and will be tested on 20 MeV neutrons from the Case Van de Graaff. It also will be flown in early 1967.

Note Added : 20 July 1966

Today we successfully completed one of the gamma ray flights scheduled for Palestine, Texas. All the equipment appears to have functioned satisfactorily and the modified anticoincidence guard increased the ratio of useful to background events by a factor of ten. The equipment was at altitude for approximately four hours after which it was cut down to prevent it from crossing over into Mexico.

We wish to thank the AEC for their generous support which made this program possible over the past six years.

FOOTNOTES AND REFERENCES

1. L. V. East, T. L. Jenkins and F. Reines, Bul. Am. Phys. Soc. II, 10, 442 (1965).
2. F. Reines, September, 1965, "Renewal Proposal for AT(11-1)-818".

BIBLIOGRAPHY

COO-818

- 79 L. H. Smith and G. M. Frye, Jr., "Cosmic Ray Electron Flux Above 4.7 BV" to be published in Physical Review.
- 80 G. M. Frye, Jr., L. H. Smith, A. A. Hruschka, J. R. Goff and A. D. Zych, "Spark Chamber for Gamma-Ray Astronomy", to be published in Review of Scientific Instruments.
- 81 G. M. Frye, Jr., and L. H. Smith, "A Photographic Spark Chamber for Manned Satellites", presented at the IEEE Meeting in Washington, D. C., February, 1965.
- 82 F. Reines, "Case Institute of Technology Cosmic Ray Neutrino Program", Congressional Report, June, 1966.
- 83 M. F. Crouch, H. S. Gurr, A. A. Hruschka, T. L. Jenkins, W. R. Kropp, F. Reines and H. Sobel, "Large-Area Liquid Scintillation Detector Slab", IEEE Meeting, Washington, D. C., March, 1966.
- 84 B. M. Shoffner and T. L. Jenkins, "Digital Pulse Height Recording for a Large Multiple Scintillation Detector Array Using an Analog Buffer Memory", IEEE Meeting, Washington, D. C., March, 1966.
- 85 M. F. Crouch, H. S. Gurr, W. R. Kropp, B. Meyer and F. Reines, "System for Recording Signal Amplitudes and Waveforms from a Large-Area Scintillation Counter Hodoscope", IEEE Meeting, Washington, D. C., March 1966.
- 86 F. Reines, "Neutrinos Underground", American Physical Society Meeting, April, 1966, Washington, D. C.
- 87 H. S. Gurr, "An Experimental Test of the Law of Baryon Conservation", Ph.D. Thesis, 1966.
- 88 G. M. Frye, "Proposal for Cosmic Gamma-Ray Flights in Australia", April, 1966 status report.
- 89 G. M. Frye, Jr., and L. H. Smith, "Upper Limits to Cosmic Gamma-Rays in the Range 30 to 500 MeV", to be published in Physical Review Letters.
- 90 F. Reines and J. P. F. Sellschop, "Neutrinos From the Atmosphere and Beyond", Scientific American, February, 1966.
- 91 F. Reines, J. Sellschop, M. Crouch and W. Kropp, "Deep Mines & Outer Space", Scientific South Africa, December, 1965.

BIBLIOGRAPHY (cont.)

COO-818

- 92 F. A. Nezrick and F. Reines, "Fission-Antineutrino Interaction with Protons", Physical Review, February 1966.
- 93 M. F. Crouch, H. S. Gurr, T. L. Jenkins, W. R. Kropp, F. Reines, G. R. Smith, B. Meyer and J. Sellschop, "The Case-Witwatersrand Underground Neutrino Program", Argonne International Conference on Weak Interactions, October 1965.
- 94 F. Reines, "Deep Lab Conference", East Rand Proprietary Mines, October, 1965.
- 95 M. Crouch, F. Reines, T. Jenkins, W. Kropp, H. Gurr, G. Smith, H. Sobel, J. Sellschop and B. Meyer, "Evidence for High Energy Cosmic Ray Neutrino Interactions", International Conference on Cosmic Rays, London, 1965.
- 96 F. Reines, M. Crouch, G. Frye, T. Jenkins, R. Woods, W. Kropp and H. Gurr, "Technical Report for Research Program in Neutrino Physics, Cosmic Rays and Elementary Particles (Contract At(11-1)-818) 1 October 1965 to 30 September 1966" July 1966.
- 97 William B. Rolnick, "Phase of the Scattering Amplitude for Charged Bosons", Physical Review, August 1966.