Project ICEF

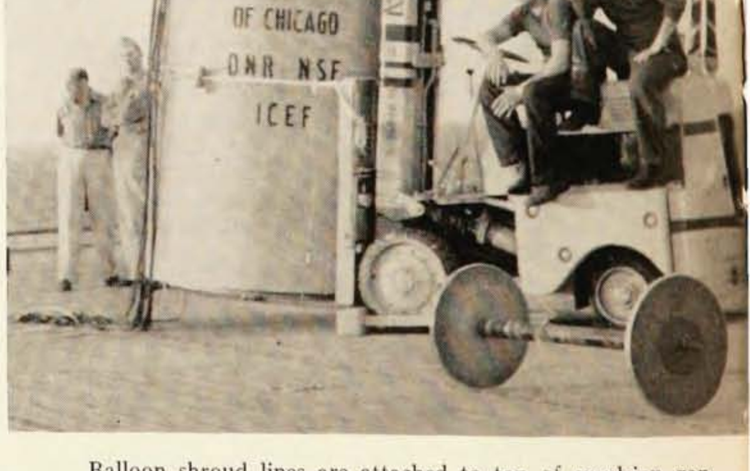
the Skyhook 60 Flights

LATE last January, an ambitious cosmic-ray experiment conducted by scientists from fourteen nations and sponsored jointly by the National Science Foundation and the Office of Naval Research was set in motion from the flight deck of the "USS Valley Forge", then cruising just east of the Leeward Islands and the Caribbean. The object was to send two Navy Skyhook balloons of unprecedented size to an altitude of 18–22 miles and to keep them aloft for two full days. Each balloon was to carry in its gondola an 800-pound stack of photographic emulsion sheets for recording primary cosmic-ray events involving energies as high as 10^{15} electron volts—energies thousands of times greater than are available in the world's largest high-energy accelerators. The Caribbean area was chosen because of its proximity to the equator, where the earth's magnetic field serves as a barrier to cosmic rays of energies lower than about 10 Bev, effectively filtering them out.

The NSF-ONR program known as "Project ICEF" (International Cooperative Emulsion Flights) spent more than a year preparing for the January expedition. The scientific work was under the direction of the late Marcel Schein, professor of physics at the University of Chicago and a seasoned veteran in cosmic-ray research and balloon launchings. The international character of the project was guaranteed by the participation of about 25 universities and other research institutions representing "every continent except Antarctica" and by the plan to divide the exposed emulsion sheets among a specified number of university groups throughout the world for the lengthy task of analyzing the results.

In mid-January, when the "Valley Forge" was about to leave its Norfolk berth for the Caribbean area, the government of France was completing preparations for its first nuclear explosion in the Sahara. Since rumors concerning the likely date of the test shot coincided disturbingly with the critical dates of the Skyhook 60 schedule, Schein had written a month earlier to F. Perrin, head of the French Atomic Energy Commission, explaining that the time from January 23 through February 5 was the crucial period for the cosmic-ray expedition and expressing the hope that the ICEF emulsions would not run the risk of being fogged by fresh fission particles in the upper atmosphere. In the absence of any reply, Schein reiterated his concern in a wire sent to Perrin just before the carrier's sailing time on January 18. Two days later, Perrin cabled Chicago that Schein's message had been passed on, and he then indicated by letter his belief that there would be no likelihood of interference with the experiment prior to February 5. The test shot in the Sahara actually took place more than a week after that date.

The first emulsion package was flown to an altitude



Balloon shroud lines are attached to top of emulsion gondola by David Haskin of the University of Chicago in preparation for launching. Project Director Schein can be seen standing at far left. (*Photos courtesy NSF*)

Battered gondola is patched up after first "Bravo" flight in preparation for second high-altitude exposure of 800-pound emulsion pack.

Skyhook balloon is inflated by tube while equipment is given last-minute check prior to launching. Ballast rack next to gondola carries sandbags and electronic control equipment.

Aircraft lifting crane holds lines attached to balloon, fed through rollers on deck. During inflation crane moves forward on deck, enabling balloon bubble to expand and rise upward.

of 116 000 feet on January 26. In its initial stages, the flight (dubbed "Bravo") was without incident, but then winds of twice the force anticipated at the 21-mile level began whipping the balloon into the southwest towards the jungles of Venezuela. The decision was reluctantly made to parachute the gondola and its cargo into the sea after a flight of only five hours at maximum altitude. The buoyant gondola was retrieved the next day and proved to be only superficially damaged, possibly by sharks. After a thorough review of the high-altitude weather situation, it was decided that a more favorable launching position must be found before the gondola could be sent up for a second exposure. The carrier accordingly set off on a two-day, 1000-mile cruise before launching "Bravo Re-Fly", as the next attempt was called. On January 30, from a point in the Caribbean south of Puerto Rico, the balloon was released and promptly rose to a peak altitude of 113 500 feet, whereupon it began a slow descent which halted twelve hours later at 61 000 feet. Ballast adjustment efforts proved ineffective and the balloon continued to hang at the same level. After nearly 27 hours, and with nightfall

Marcel Schein, director of the international cosmic-ray project described here, died on February 20 at the age of fifty-seven. He was professor of physics at the University of Chicago and at the University's Enrico Fermi Institute for Nuclear Studies, where he achieved world-wide recognition for his high-altitude studies of primary cosmic-ray particles. He had returned to Chicago after the Skyhook 60 flights in the Caribbean area in January and was enjoying a brief respite at home between expeditions. While at the ice skating rink at Stagg Field on the University campus he was stricken with a heart attack, and his death came several days later at Billings Hospital. Born in Trstena, Czechoslovakia, he received his doctoral degree from the University of Zurich in 1929. He was in the Soviet Union as professor of physics at the University of Odessa from 1935 to 1938, and in the latter year he came to the United States to join the University of Chicago faculty. An enthusiastic proponent of cosmic-ray research, he was largely responsible for the organization of a summer institute for cooperative emulsion research conducted in Chicago. He also assisted the Apparatus Committee of the American Association of Physics Teachers in its program for distributing exposed nuclear emulsions for study in college physics departments by contributing a considerable number of plates exposed during high-energy experiments in which he had participated. He was a fellow of the American Physical Society.

approaching, the gondola was again parachuted down and recovered.

Meanwhile, during an attempt to launch the second emulsion stack, balloon "Charlie" snapped its load tapes and fell into the sea. Shortly thereafter, with all hopes depending on the emulsion exposed for a total of nearly 32 hours in the two "Bravo" flights, the research group returned home and the work of processing the plates was begun. Analysis of the 500 sheets of emulsion contained in the one stack is expected to take about two years.

The death of Marcel Schein three weeks after the Skyhook 60 flights was a serious blow to Project ICEF. At this writing it is not known who will succeed him as director of the project, but the work, in any event, is continuing. Because photosensitive materials deteriorate with time, it was essential that steps be taken quickly to prepare for a new launching of the unexposed emulsion, and Schein was occupied with that problem before his death. At last report, arrangements had been made for the second emulsion to be flown in the southwestern United States sometime next month.

On December 26, 1959, Marcel Schein presented a 50-minute paper on the subject of "High-Energy Particles in the Cosmic Radiation" at the 126th meeting of the American Association for the Advancement of Science in Chicago. His own abbreviated summary of that talk (as given in the publication *University of Chicago Reports*, **10**, 4–5, 1960) is reproduced below.

THE studies of cosmic-ray phenomena contributed a great deal to our knowledge of elementary particles of the physical world. Most of the new particles were discovered in the cosmic radiation. As a consequence, large accelerators were constructed in the multibillion-electron-volt energy range which enable us to carry out detailed investigations of the new particles under controlled conditions. Indeed, the work with accelerators yielded a number of most important new results regarding the nature of these particles which contribute to our understanding of the general problem of the structure of matter. The largest accelerator in existence is the one at CERN, Geneva, Switzerland, in which particles are accelerated up to an energy of 25-billion electron volts. Beyond that the only source of still higher-energy particles is the cosmic radiation, which is one of the most spectacular phenomena in nature.

Our recent studies show that direct observations on primary cosmic-ray particles can be carried out up to an energy of one million times one billion electron volts, which is more than ten thousand times the energy of the CERN machine. Hence it will take a very long time before techniques can be developed in which elementary particles can be artificially accelerated to these extremely high energies. It is then of great importance to explore the physical laws and the nature of matter under the bombardment of these extremely high energies.

The only method available to study the elementary act of interaction is the use of large blocks of pure nuclear emulsion, exposed to the primary cosmic radiation, close to the top of the atmosphere.

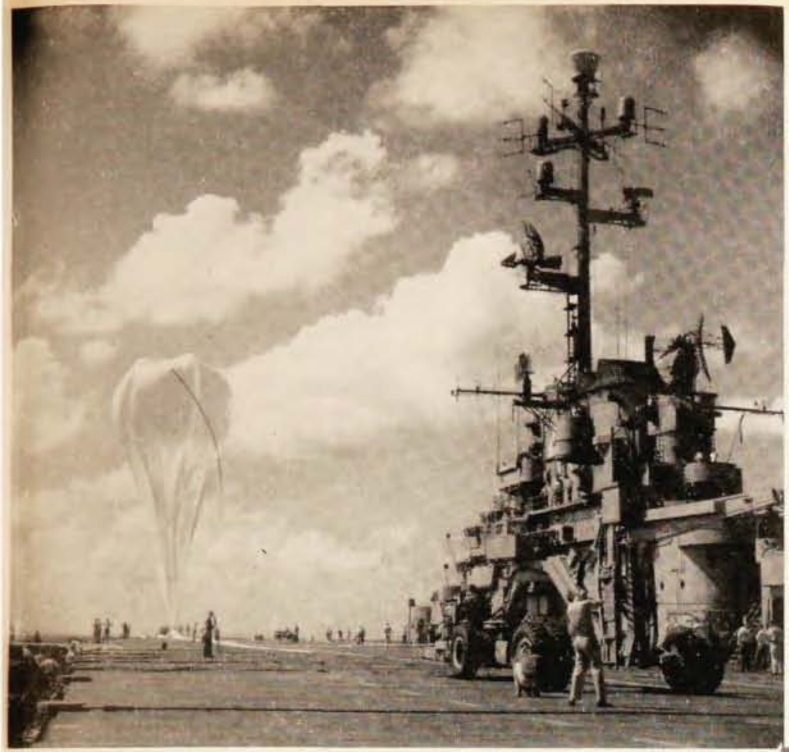
Our most recent data—from 1958 experiments—reveal a number of interesting new results, and some of the important parameters have been determined which make a direct comparison possible with theories proposed by Fermi, Heisenberg, Landau, and Oppenheimer. Measurements of the multiplicity of the meson production, the energy distribution of secondary particles, the transverse momentum, and the elasticity yield results which are in disagreement with the various theories. Hence it is our opinion that a new theoretical approach will be needed before deeper understanding of nuclear phenomena at extremely high energies will be possible.

In general, it is proposed that one should consider three kinds of collisions between nucleons at the very high energies. By subdividing the nucleon into a small core in the middle, surrounded by a cloud of pi mesons, and applying relativity to the fast moving systems, one comes to the conclusion that the collisions fall into the following categories: (1) pi-pi interactions; (2) pi-core interactions; and (3) core-core interactions.

None of these has been studied in great detail, and we believe that it will be a new step in physics to be able to carry out thorough studies of these new phenomena. In particular, core-core collisions of nucleons, which have never been observed so far, should be of greatest interest, in order to see whether a new dimension much smaller than the range of nuclear forces may have to be introduced in physics in order to understand the behavior of elementary particles.

Hence we feel that the ultimate aim of these studies is to find out whether our present space-time structure is adequate to describe interactions between elementary particles at extremely high energies. It is our plan to carry out an experiment ["Skyhook 60"] with the support of the National Science Foundation and the Office of Naval Research in which several thousand collisions at extremely high energies can be studied in unusually large blocks of nuclear emulsion exposed to the primary cosmic radiation.

In addition, it is of considerable interest to cosmology to find out where the cosmic rays originate and by what mechanism they gain their energy. New data



At left, with inflation tubes tied off and dangling, the Skyhook balloon "Bravo Re-Fly" is slowly fed through rollers on deck of the aircraft carrier "Valley Forge", restrained by lines running back to the mobile crane in right foreground. As seen moments before launching, below, the crane has moved forward, allowing the balloon to stand up nearly 500 feet above deck. Emulsion stack carried in the gondola had been exposed to cosmic radiation for about five hours in an earlier ascent, and during this flight received an additional 27-hour exposure at high altitude.

on the composition of the primary cosmic radiation will be presented. In addition, the energy spectra of the heavy nuclei will be described up to energies of a hundred billion electron volts per nucleon. The data show that the abundances of very heavy elements, like iron, are much more prominent in the cosmic radiation than on the sun. Hence the sun cannot contribute to the bulk of the radiation. This is also ruled out by the fact that we observe energies at least one million times one billion electron volts, which cannot be generated on the sun. On the other hand, it will be shown that there are objects in our galaxy which can easily generate particles of extremely high energies and which show high abundances of heavy elements. We believe that supernovae, like the Crab Nebula, and some other active stars in the early stages of their development are good candidates for generating cosmic rays.

We also studied the problem of whether antimatter, in the form of heavy nuclei, enters from the outside in the form of cosmic rays. About one thousand clear-cut cases have been investigated. However, no presence of antimatter has been found so far. This indicates that the amount of antimatter in our own galaxy is very small and possibly negligible. Naturally, this could be due to the fact that matter and antimatter in close contact do annihiliate instantaneously. Further studies will be made in this direction; in particular, a search for radiations coming from outside our galaxy will be investigated. Electron cascades arising from gamma rays from outer galactic space, which are not scattered by the magnetic fields in our own galaxy, should yield results in this direction, since the annihilation of matter and antimatter arising, for instance, from the collision of a galaxy with an antigalaxy should yield a large number of neutral pi mesons, which spontaneously disintegrate into gamma rays after the very short time of one ten-million-billionth of a second.