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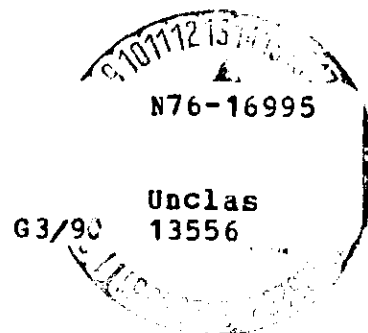
Semi-Annual Report
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RELATIVISTIC ASTROPHYSICS

Principal Investigator
Professor P. Buford Price

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February 10, 1976

Space Sciences Laboratory Series 17, Issue 7

1. Publications and Progress Report from November 1974 to July 1975.

Publications during the 8 month period November, 1974 to July, 1975

1. The University of California Iron Isotope Experiment. S.P. Ahlen, B.G. Cartwright, H. Crawford, P.B. Price, and G. Tarlé, Proc. 14th inter. Cosmic Ray Conf. (Munich, Germany) (1975), to be published.
2. Sonic Spark Chambers for Cosmic-Ray Experiments. S.P. Ahlen, B.G. Cartwright, P.B. Price and G. Tarlé, Proc. 14th Inter. Cosmic Ray Conf. (Munich, Germany) (1975), to be published.
3. Measurements of Ultraheavy Cosmic Ray Nuclei from Detectors on Skylab. E.K. Shirk and P.B. Price, submitted to Phys. Rev. Letters (1975).
4. Composition and Energy Spectra of Heavy Nuclei of Unknown Origin Detected on Skylab. J.H. Chan and P.B. Price, submitted to Phys. Rev. Letters (1975).
5. Search for Ultradense Nuclei in Collisions of GeV/nucleon Ar + Pb. P.B. Price and J. Stevenson, Phys. Rev. Letters 34, 409 (1975).
6. Reply to Pellas and Storzer (article entitled "Plutonium-244 Fission Tracks: An Alternative Explanation for Excess Tracks in Lunar Whitlockites"). I.D. Hutcheon and P.B. Price, Science 187, 864 (1975).
7. Track Studies Bearing on Solar System Regoliths. P.B. Price, I.D. Hutcheon and D. Braddy, submitted to Proc. Sixth Lunar Sci. Conf. (1975).
8. Crystal Chemistry of Pu and U and Concordant Fission Track Ages of Lunar Zircons and Whitlockites. D. Braddy, I.D. Hutcheon and P.B. Price, submitted to Proc. Sixth Lunar Sci. Conf. (1975).
9. Particle Track Studies Using Electron Microscopy. I.D. Hutcheon and D. Macdougall, Applications of Electronmicroscopy in Mineralogy (ed. H.R. Wenk) Springer Press, to be published.
10. Micrometeorites and Solar Flare Particles In and Out of the Ecliptic. I.D. Hutcheon, Interactions of the Interplanetary Plasma with the Modern and Ancient Moon (ed. D.R. Criswell and J.W. Freeman) pp. 82-84, Lunar Science Institute, Houston (1974).

11. Microcraters In Oriented Vugs-Evidence for an Anisotropy In the Micrometeoroid Flux. I.D. Hutcheon, Lunar Sci. Sixth, pp. 420-422, Lunar Science Institute (Houston) (1975).
12. Fission Track Record of Apennine Front KREEP Basalts. E.L. Haines, I.D. Hutcheon, and J.R. Weiss, submitted to Proc. Sixth Lunar Sci. Conf. (1975).
13. Micrometeorites and Solar Flare Particles In and Out of the Ecliptic. I.D. Hutcheon, J. Geophys. Res., to be published (1975).
14. Consortium Studies of Matrix of Light Gray Breccia 73215. O.B. James, A. Brecher, D.P. Blanchard, J.W. Jacobs, J.C. Brannon, R.L. Korotev, L.A. Haskin, H. Higuchi, J.W. Morgan, E. Anders, L.T. Silver, K. Marti, D. Braddy, I.D. Hutcheon, T. Kirsten, J.F. Kerridge, I.R. Kaplan, C.T. Pillinger and L.R. Gardiner, submitted to Proc. Sixth Lunar Sci. Conf. (1975).
15. Radiation Pressure Exerted by Resonance Lines. R.H. Gordon, submitted to Astrophys. J. (1975).
16. The Nested Leaky Box Model for Galactic Cosmic Rays. R. Cowsik and Lance W. Wilson, Proc. 14th Inter. Cosmic Ray Conf. (Munich, Germany) (1975) to be published.
17. Supernovae as Cosmic Ray Sources. R. Cowsik and Lance W. Wilson, Proc. 14th Inter. Cosmic Ray Conf. (Munich, Germany) (1975) to be published.

Progress Report for the 8 month period November, 1974
to July, 1975

The above list of publications gives some indication of our activities during the last eight months. We now discuss in detail the status of IRIS and give a briefer account of other unpublished work in progress.

1. Resolution of Iron-Group Isotopes in the Cosmic Rays

Growth in our understanding of a wide variety of violent astrophysical processes, including nucleosynthesis, late stellar evolution, the supernova explosion and resulting remnants, and the history of the interstellar medium, requires a knowledge of the isotopic composition of the elements at the endpoint of thermonuclear nucleosynthesis, the elements near iron. The carbonaceous

chondrites are so far the only source of "universal" isotopic abundances in this charge region, but analysis of their composition is hindered by uncertainties concerning their chemical and physical history. Today, iron-group nuclei in the cosmic radiation represent the sole source for unambiguous information with which to probe these exciting processes. As a result, the possibility that isotopic composition data may soon be available has evoked great interest among a large number of astrophysicists, including many outside the traditional cosmic-ray community.

We have undertaken an experiment (dubbed IRIS, for IRon ISotopes) which uses a novel design capable of performing direct measurements of the relative abundances of individual neighboring isotopes at charge 26. Such a measurement requires an instrument of resolving power unprecedented in the cosmic-ray field. As a result, many experimenters have chosen to attack this problem indirectly--either by attempting to measure only the atomic weight, or "mean mass" of iron group nuclei, or by building a series of experiments of gradually increasing resolution with which to work slowly up the periodic table in the direction of iron. We, on the other hand, have developed a new technique with which we feel confident we can resolve neighboring isotopes at iron with the large geometrical factor required for a balloon-borne instrument. Since no comparison with other instruments in mass-resolving power is possible (no such measurements have been made or projected for balloon-borne instruments), we feel that our calculated charge resolution best provides a comparison with the current generation

of experiments. Based on calibration at the Lawrence Berkeley Laboratory Bevatron and on an exhaustive analysis of our errors, we estimate the separation between charge 25 and charge 26 to be in the worst case at least five standard deviations with our technique. As only in the last few years has any convincing separation of Mn and Fe been achieved in any energy range using either satellite or balloon platforms, we feel IRIS represents a new generation of cosmic-ray detector.

IRIS-II is now instrumented with state-of-the-art electronics. The heart of the flight package is the pulse-code modulation encoder. The encoder has a bus architecture, with each data source responding to a unique address. Readout sequencing is directed by a programmable read-only memory. The encoder is equipped to process either analog or digital data with either linear or logarithmic conversion. Thus, each data source connected to the bus is addressed in turn under sequence control by the pROM, which also contains information which characterizes the source as analog (say, a gondola temperature), requiring conversion, or digital, requiring only bi-phase generation and direction to the transmitter. Re-programming of the pROM can completely alter the sequencing so as to radically alter the telemetry format. Although the system as designed and built can operate at data rates over 100 kb/s, IRIS-II will use a basic 8192 b/s data rate, providing eight telemetry sequences per second. This rate can be accommodated by IRIG channel H, as provided by balloon launch organizations (either NCAR or Raven). Each sequence is divided into eight frames of

sixteen eight-bit words. Since the events of interest are relatively infrequent, much of the telemetry is consumed by frequent calibration signals, which are generated both electronically, and by radioactive sources in contact with scintillators placed inside the light integration and diffusion chambers which surround S2 and CK. The system calibrates itself to sub-one-percent accuracy in under 5 minutes.

All electronics with the exception of power supplies and photomultiplier tube preamplifiers is housed inside a carefully designed low interference box which is hermetically sealed with EMI gaskets and RF feedthroughs to insure immunity against the blast of EMI generated by the sparks in the optical spark chambers. The pulse height analyzers, which are required to discriminate 5 mV in the presence of this spark noise, store a charge proportional to the pulse height on a capacitor which is isolated by an analog gate during the time interval of the spark noise. Careful design of ground planes and multiply-shielded input stages have permitted us to operate these analyzers even during the time interval when the spark noise is present. The analyzers maintain an integral gain constant to 0.2% over the specified temperature range.

Arcillary control and timing circuitry housed within the same box performs the operations necessary to sequence the optical spark chamber cameras, prevent acceptance of a second event during camera sequencing, accept actual events on a priority basis after a calibration event has occurred, etc. Commands permit the experimenter on the ground to substitute redundant power supplies, analyzers, and other circuitry, should an in-flight failure occur.

The IRIS-II Ground Support Equipment (GSE) is a highly sophisticated, extremely flexible data acquisition and display system. It has been developed as the end product of several generations of ground stations used in the Space Sciences Laboratory in the rocket and balloon programs of several groups. As a result, the design costs assessed against this project are a tiny fraction of the true development cost of the GSE. Even in this instance, we are sharing the costs of design and construction of our unit with two other groups who are constructing interchangeable units of their own. Thus, when we fly IRIS-II, we will borrow a second GSE for use as a down-range station.

The front end of the GSE is a sophisticated phase-locked loop which can lock on extremely weak signals of S/N of about one by reference to sync words transmitted as the first two words of our telemetry sequence. Lock criteria are switch selectable to permit a wide range of signal-to-noise ratios to be optimally accommodated. The incoming data stream is decoded under pROM control, with front panel switches determining the number of bits per word, the number of words per frame, and the number of frames per sequence. De-commutated analog data are reconstructed under pROM control by a DAC in conjunction with sample/hold circuits and are available at rear panel BNC connectors. Which analog signal appears at which BNC connector is determined by a RAM which is loaded from the front panel. Digital data are merged on a word-by-word basis with their address sequence and are available at the rear panel for parallel transmission to a computer, in our case a PDP-11/10 in

the field, or a PDP-11/40 in Berkeley. In addition digital data may be displayed on an LED readout on the front panel. Finally, the merged digital data are also presented simultaneously to an Intel 8080 microprocessor housed within the same box. The microprocessor is controlled by teletype, and has been programmed to accumulate pulse-height spectra on-line. Soon, it will be programmed to detect the movement of housekeeping data outside of pre-set limits. Thus, it will warn the experimenter instantly if a voltage or temperature strays outside of specification during flight. Once again, we have benefited greatly from our strong interaction with other groups in Space Sciences Laboratory: In this case, the basic hardware and software design of the microprocessor system was undertaken by another group. We are merely copying their development and adding our own software for our own purposes.

It should be stressed that this ground station is useful not only as an on-line station during flight but also for post-processing of the flight magnetic tapes after we return to Berkeley. For example, by running the flight magnetic tapes through the ground station we can "peel off" desired portions of the data, say, all pulse-height information, for output onto a second, far more compact tape for processing by a large computer. The extreme flexibility of the system should make it quite useful for accelerator experiments and calibrations as well.

Finally, it should be noted that all critical information about each event is encoded onto the optical spark chamber film,

so that even in the event that telemetry is lost, the experiment will continue to provide useful science.

IRIS-II will measure the isotopic composition of iron-group nuclei by means of a novel combination of active and passive particle detectors. These detectors include two optical spark chambers (8 sparks total), three organic scintillators, one Cerenkov counter and a range stack consisting of 350 5-mil sheets of Lexan. A complete description of the instrument appears in the first of two attached papers which will be presented at the 14th International Conference on Cosmic-Rays in Munich in August. In brief, charge determination is to be accomplished by means of the Cerenkov vs. dE/dX mode and mass resolution will be achieved by the Cerenkov vs. Range mode. Extremely accurate range measurements are obtained by analysis of etched particle tracks in the Lexan range stack.

The instrument described in the first attached paper is the revised version of a prototype flown in September, 1974. The new mechanical design features a Cerenkov-scintillator-range stack module with flatness and dimensional tolerance of ± 10 mils. This accuracy is imperative because of our requirements for particle location in the range stack and for accurate assignment of range.

The S2 scintillator will now be made of Pilot-F. Tests performed with atmospheric muons, Am^{241} alpha particles and minimum ionizing carbon and argon beams at the Berkeley Bevalac indicate that saturation effects are least significant in Pilot-F. Hence,

to optimize charge resolution, we have chosen to use this material.

Investigations into alternative schemes for an accurate hodoscope led us to the conclusion that an acoustic spark chamber would be optimal for our experiment. A complete discussion of this is found in the second attached paper. It will be noted there that 0.1 mm accuracy is attainable. Although highly desirable, we have decided not to implement such a system into IRIS-II because of the additional cost involved.

In the past month an exhaustive analysis of the resolution capabilities of IRIS-II has been completed. All possible sources of intrinsic error have been considered. These include statistics of photoelectron and secondary electron emission, particle deflection due to multiple coulomb scattering, energy loss fluctuations in the Cerenkov and scintillation counters, range straggling in the Lexan range stack, saturation in the Pilot-F scintillator, fluctuations due to nonuniform delta-ray production in matter above the electronic counters, and deviation from the standard Cerenkov law $Z^2(1 - \frac{1}{n^2\beta^2})$ due to knock-on electrons above the Cerenkov threshold produced in the Pilot 425 Cerenkov radiator and the matter directly above it. We considered the possibility of residual scintillation in the Pilot 425 radiator and found it to be very small; the experimental results of Sacharidis (reference in 1st attached paper) can be explained in terms of delta-rays emitting Cerenkov light. For our analysis a saturation curve for Pilot-F was estimated using our experimental results with 1.8 GeV/N Ar and 2.1 GeV/N C^{12} beams at the Berkeley Bevalac (corrections were

made for delta-ray escape losses using a simple, relativistically correct formula for the delta-ray escape spectrum).

The results of our analysis follow:

1) Range determination is without error relative to other measurements because of the miniscule amount of range straggling (0.13% for 300-500 MeV/N Fe⁵⁶).

2) The only important sources of Cerenkov error are photoelectron fluctuations and delta-ray inhomogeneities. These errors are comparable in magnitude. However, the delta-ray errors can be partially corrected and hence reduced.

3) The only important sources of scintillator errors are photoelectron fluctuations and energy loss fluctuations, which are comparable in magnitude. These errors are very small due to the fact that the S2 scintillator is immediately above the range stacks and hence is "thick" for the slow iron particles. This also explains the relatively unimportant delta-ray degradation (delta-ray escape losses go down with particle energy).

4) Delta rays that emit Cerenkov light contribute a Cerenkov signal component linear with particle velocity. The level is low enough so that resolution is not seriously effected. Charge separation provides a comparison with previous experiments. Separation of Fe from Mn by five standard deviations is attainable for energies above 380 MeV/amu with the Cerenkov vs. dE/dX mode. Comparable accuracy can be obtained with a Range vs. dE/dX mode.

2. Ultraheavy Cosmic Rays

The first phase of our Skylab "Transuranic Cosmic Rays" experiment was completed with the submission of a brief account

to Physical Review Letters. The charge resolution fulfilled our hopes: as Fig. 1 (next page) shows, we have an actinide gap with no data for the short-lived radionuclides $84 \leq Z \leq 89$, we have a peak at uranium, and a small contribution of transuranics. The composition is consistent with pure r-process.

We are well into the analysis of balloon-borne Lexan stacks flown almost two years ago with W. Z. Osborne and co-workers. We are proceeding with this analysis, in spite of the obvious success of our Skylab experiment, because there appears to be one extraordinarily heavy track in the emulsion layer scanned by Osborne. Peter Fowler has seen the track and believes it is a more heavily ionizing event than any he has reported!

3. Energetic heavy nuclei in the trapped radiation

In our analysis of tracks in one Lexan module exposed 73 days outside the Skylab, we discovered an intense flux of particles including oxygen, neon and heavier elements extending up to iron. We have presented our findings at an AGU and an APS meeting and have had a short report accepted by Physical Review Letters.

4. Relativistic Heavy Ion Reactions

As we pointed out last year, relativistic heavy ion experiments offer the hope of simulating processes deep inside neutron stars, as well as of making entirely new phases of nuclear matter.

We reported in Physical Review Letters an important negative search for an abnormally dense phase of nuclear matter predicted by T. D. Lee and G. C. Wick. We used the first (and only) beam of 80 GeV argon ions at the Bevalac. One important positive result of the experiment was the surprising observation of events

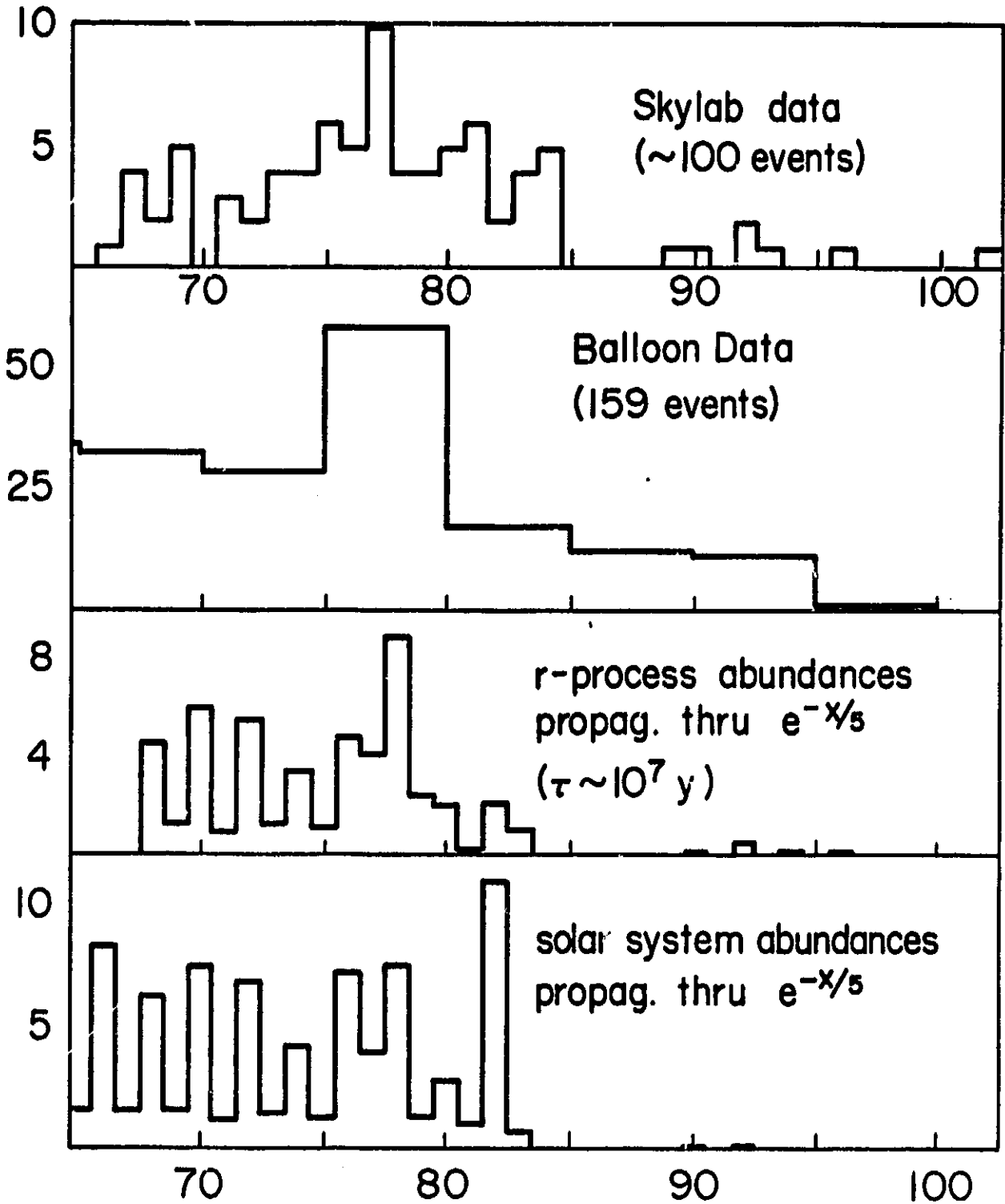


Fig. 1

in which argon penetrated lead nuclei and emerged in the forward direction with low transverse momentum but the loss of a large fraction of their longitudinal momentum. Qualitatively an argon nucleus seems to act somewhat as a proton does in a high-energy interaction: it has a small transverse momentum and a large inelasticity.

We have just completed a successful exposure of huge stacks of Lexan detectors in the reaction 1.05 GeV/nucleon $^{16}\text{O} + \text{U}$ and $^{16}\text{O} + \text{Ag}$, where we can determine cross sections for heavy fragment emission as a function of emission angle, energy (up to 200 MeV/nucleon) and charge ($Z > 3$).

5. Laser-Enhanced Improvement in Telescope Resolution

With a new student, M. Salamon, we are continuing to study the feasibility of this scheme. We shall shortly submit proposals to the NSF and to ARPA for funding.

6. Capture and Loss of Orbital Electrons by Relativistic Heavy Ions

At very high energies an ion passing through matter is completely stripped. The mean free path for electron pickup, λ_g , is much larger than the mean free path for electron loss, λ_l . As the particle slows λ_g decreases more rapidly than λ_l so that the ion begins to pick up electrons. For each charge Z there is a kinetic energy per nucleon $E_{\frac{1}{2}}(Z)$ at which $\lambda_{\frac{1}{2}} = \lambda_g = \lambda_l$. Using the standard formulas evaluated for Lexan ($\text{C}_{14}\text{H}_{16}\text{O}_3$), $E_{\frac{1}{2}}$ and $\lambda_{\frac{1}{2}}$ increase from ~ 1 MeV/amu and ~ 100 Å for C to ~ 900 MeV/amu and ~ 1 mm for U. Since the range of a 1 GeV/amu uranium in Lexan is 8 cm and our Skylab detectors are ~ 0.8 cm thick, we would expect the occurrence of

several charge changes in those events with energy near $E_{\frac{1}{2}}$. The fluctuation $\Delta Z = 1$ should be observable as a ~4-5% change in the etch rate, which our measurements could surely resolve. We do not find the predicted fluctuations. Without performing a detailed analysis it seems that the mean free paths calculated with the standard formula are either much too large or much too small. Simply by looking carefully at existing data we hope to learn more about this problem, which is important to the understanding of isotopic abundances of elements such as Fe, some isotopes of which are stable if completely stripped but can decay by K-capture if K electrons are present.

7. Nested Leaky Box Model of Cosmic Ray Confinement and Propagation

Radiative electron pickup, that is, the simultaneous pickup of an electron from the interstellar medium and the emission of a photon, has been incorporated in the propagation calculation for the nested leaky box model. Even though previous workers omitted the process, the cross section turns out to be large even at kinetic energies ≥ 1 GeV/nuc. Also both the flux of high energy γ -rays and the spectrum of synchrotron radio emission from cosmic rays contained in the inner leaky boxes (the sources) have been calculated. The definitive exposition of the model is under preparation as L. Wilson's thesis.

8. Radiation Pressure Exerted by Resonance Lines

R. Gordon has investigated the accuracy of various approximations in solving the equation of transfer for a single resonance line and has determined the dependence of the radiative force on

optical depth in an irradiated slab of scattering material. (See paper 15). He employed these solutions in a model of the acceleration of clouds near QSO's by continuum and line absorption. He studied the internal structure of the cloud and sought conditions for the onset of Rayleigh-Taylor instabilities. In his Ph.D. thesis, which he expects to complete by September, he is pursuing the possibility that these instabilities are suppressed or reduced in the case of radiative acceleration of clouds. It should be possible to limit the range of allowed models of clouds near QSO's.

II. Current Status of IRIS (Iron Isotopes Experiment)

During the past six months we have continued to prepare IRIS for launch during Spring Turnaround of 1976.

A most important part of this effort has been the exposure of the active detectors to argon and neon ions at the Bevalac. The actual response of both scintillators and cerenkov counters to heavy ions has been somewhat uncertain in the past. These exposures were designed to remove as much of this uncertainty as possible, to study the actual response of such detectors as a function of energy under laboratory conditions, and to prove the design of our flight systems.

First, we were given a brief (a few hours) exposure to the new, and very valuable, argon beam now available at the Bevalac, at an energy of 334 MeV/nucleon. This energy falls just below the threshold of the critically important cerenkov detector in our experiment, and is therefore ideal for studying the portion of the total signal from a cerenkov counter which does not arise from cerenkov emission, and which therefore reduces resolution significantly. For this purpose the high Z^2 of argon (324) was essential since these effects are quite small but scale with Z^2 .

Second, we were given two shifts of neon at 594 MeV/nucleon as an approved Bevalac experiment. This beam energy was also ideal since it provided us with the capability necessary to study the response of our detector systems throughout their range of useful resolution by slowing the beam in varying thicknesses of lead sheets. Highly precise measurements were, in fact, made at 19 different entrance energies and at a variety of angles of incidence.

These tests represent one of the first careful studies of the response to heavy ions of a high resolution cerenkov intensity counter and are of interest to others as well as to ourselves both because they indicate the truly outstanding resolution possible with an optimum cerenkov detector design and because they represent one of the first detailed studies of the actual response of a cerenkov counter to heavy ions as a function of energy. Cerenkov detectors, of course, do not respond as expected from the classical cerenkov law; the actual response being influenced in small but very significant ways by the cerenkov emission of delta rays and by residual (but saturated) scintillation.

We are at present preparing a paper on the experimental response of cerenkov detectors to heavy ions as well as a theoretical and calculational analysis of how to predict this response without consuming vast quantities of computer time in extended numerical integrations. This information should prove to be quite useful in the coming years.

In addition we have been able to demonstrate the truly excellent properties of our flight cerenkov counter design:

- 1) Despite the directionality of cerenkov emission, we can detect no variation in signal with angle of incidence other than that associated with the secant of the angle and the slowing of the particle. (We can detect variations well under 1%, should they exist.)
- 2) The uniformity of response as a function of position of incidence over the cerenkov radiator is limited by the variations in thickness of the radiator and is less than 1% peak-to-peak.

- 3) The uniformity of response above has been achieved without reduction in light collection efficiency: the system figure-of-merit is 37 photoelectrons per cm.
- 4) The increase in cerenkov output near threshold (critical to our immediate experimental goals) has been verified to be dramatic and sufficient for our purposes (see accompanying lab graph).

The means by which we achieved this excellent response will be described in detail in a forthcoming paper.

At the present time we are preparing for the shipment of our IRIS experiment to the launch site sometime during the week of 22 March 1976. The approximately eight weeks between then and now will be primarily spent in extensive testing of the apparatus. We intend to cool the entire eight-foot diameter gondola sealed as for flight to -10°C as part of these tests, for example.

III. Status of the Monopole Experiment

GA 2. Magnetic Monopoles: Can They Be Seen?*
SIDNEY A. BLUDMAN, University of Pennsylvania. (40 min.)

The persistence of the nearby interstellar magnetic field limits the monopole birth rate in our galaxy to $<10^{-37}$ poles $\text{cm}^{-3}\text{s}^{-1}$. For electrically neutral magnetic monopoles or dyons of energy above 3×10^4 Gev or for highly electrically charged magnetic monopoles of energy above 2×10^6 Gev, the theoretical flux limits derived are lower than those set by monopole searches in lunar rocks. Since the average energy gained by cosmic monopoles from the interstellar field is $>10^{11}$ Gev, they can be detected nonrelativistically only if their mass $M \sim 10^{11}$ Gev/c². Magnetic monopoles are possible at the recently reported flux level if they have been trapped in dust grains, and if their energy and mass exceed 3×10^6 Gev. Such large masses are conceivable for an elementary 't Hooft monopole.

*Assisted in part by the Energy Research and Development Administration.

GA 3. The Magnetic Monopole: Fact or Fiction?*
P. BUFORD PRICE, University of California, Berkeley. (40 min.)

In Phys. Rev. Lett. 35, 487 (1975), Price et al. reported evidence for a monopole with $g=137e$, $\beta=0.50 \pm 0.05$, and mass >200 Gev. This event stands out distinctly from the ~ 200 ultraheavy ($Z>70$) cosmic rays studied with track detectors of total collecting power $\sim 3\text{m}^2$ y on balloons and Skylab. The corrected stack thickness is 1.37g/cm^2 ; the calibrated Lexan track etch rate in $\mu\text{m/h}$ is $1.09 \times 10^{-10} (Z_{\text{eff}}/\beta)^{3.07}$; and the etch rate of the monopole candidate roughly constant at $\sim 2.9\mu\text{m/h}$, corresponds to that of a nucleus with $Z_{\text{eff}}/\beta=114$ (not 137, as reported). From S. Ahlen's unpublished analysis of velocity dependence of monopole ionization rate, our data are consistent with a monopole of magnetic charge $g/e=130.4 \pm 5$ and a mass >600 Gev. Others have suggested that the data are consistent with a sawtooth Bragg curve of a multiply fragmenting nucleus with initial $Z=78$, $\beta=0.7$. We have now measured eight new points in Lexan sheets at the top and bottom of the stack, bringing the total to 66, and have used numerous tracks of iron and ultraheavy cosmic rays to calibrate the sensitivity of individual sheets. In the absence of any constraints on velocity imposed by the other detectors or any probability arguments, the Lexan data would be compatible with such combinations as $Z=110$, $\beta=0.97$; $Z=96$, $\beta=0.86$; a once-fragmenting $Z=92$, $\beta=0.82$; a triply fragmenting $Z=83$, $\beta=0.74$; or a quadruply fragmenting $Z=79$, $\beta=0.70$. If the upper limit $\beta \leq 0.70$ imposed by the absence of spots in the two Cerenkov films is valid, all but extraordinarily improbable combinations of Z , β , and number of fragmentations can be ruled out. We are now using a computer-driven optical system to measure the radial distribution of silver grains at tracks of heavily ionizing particles in the emulsion and in the Cerenkov films. This provides two estimates of velocity that can be compared with measurements on the same nuclei in the Lexan stack. The outcome of these tests, together with analyses of probabilities of occurrence of various scenarios and goodness of fit of their curves to the data, may enable the speaker to answer the question posed in the title. Plans for other monopole searches will be discussed.

*Supported by ERDA and NASA.

GA 4. The Electric and Magnetic Dipole Moments of the Neutron.
NORMAN F. RAMSEY, Harvard University. (40 min.)

A neutron beam magnetic resonance experiment has recently been completed at the Institut Laue-Langevin reactor at Grenoble, France, by scientists from France, U.K. and U.S. which markedly lowers the experimental upper limit to the neutron electric dipole moment. The experimental value is $\mu_E/e = (0.4 \pm 1.1) \times 10^{-24}$ cm. Although time reversal invariant theories predict a zero value for μ_E , most theories that account for the CP violating decay of the K_2^0 predict a value of μ_E larger than the limit set by the above measurement with the dominant exception being theories that attribute the CP violating decay to a super-weak force. Preparations are now being made for a new version of the neutron resonance experiment utilizing ultra-cold neutrons trapped by total reflections in a neutron bottle. While the ultra-cold neutron beam is being prepared at Grenoble, the present apparatus is being used for an improved measurement of the neutron magnetic dipole moment. Experiments are also planned to observe the small parity violating precessions of the neutron that occur on the passage of neutrons through matter due to the parity violating weak force¹ and somewhat larger effect when the matter is optically active.²

1. F. C. Michel, Phys. Rev. 133, B329 (1964) and L. Stodolsky, Max Planck Institute, MPI-PAE/Pth9 (1974).

2. P. K. Kabir, G. Karl and E. Obyrk, Phys. Rev. D10, 1471.

WEDNESDAY MORNING, 4 FEBRUARY 1976
 WEST BALLROOM AT 9:00 A.M.
 D.O. Thompson, presiding

CONCURRENT CONFERENCE: MATERIALS RESOURCES AND
 MATERIALS SCIENCE
 TECHNOLOGY OF MATERIALS SUBSTITUTIONS

GB 1. Technology and Materials Substitution.
ROBERT U. AYRES, International Research and Technology Corporation. (30 min.)

There are a host of possible topics which can be discussed under this heading. The paper will attempt to classify the functional uses of materials in relation to their properties. It will then sketch the outlines of an explanation of the current pattern of utilization.

The Magnetic Monopole: Fact or Fiction?

Rough Synopsis of Press Conference - February 3, 1976

American Physical Society Meeting, New York

Original Claim:

We detected a unique particle with $Z/\beta \sim 137$, with $\beta \sim 0.5$ and with no detectable change in Z/β through our detectors. No nucleus can account for the data. The particle behaves like a magnetic monopole with strength $137 e$ and mass $>200 m_p$.

Subsequently:

Our calibration of the Lexan detectors indicated a downward revision of Z/β to ~ 114 . S. Ahlen calculates that this could be consistent with the effect of a monopole of speed $\beta \sim 0.5$ in a plastic detector. Alvarez found that we had overestimated the thickness of inert material in our stack of detectors.

Criticism of the Claim:

P. Fowler: "Nuclear emulsion cannot tell the velocity at $\beta > .45$."

R. Fleischer, P. Fowler and L. Alvarez: "If we disregard the emulsion measurement and the data in the top Lexan sheets, a twice fragmenting nucleus with $\beta \sim 0.7$ would be compatible with the Lexan data and would not trigger the Cherenkov detectors. There have been searches a million times more sensitive which have failed to detect monopoles."

Response of the Authors:

With the correct stack thickness and individually calibrated sheets, the 58 original Lexan points, plus 8 new points, rule out a twice fragmenting

platinum nucleus and make it extremely unlikely that any nucleus, fragmenting up to three times at any β up to 0.8, could have caused the event. The Lexan data alone cannot, however, rule out a curium nucleus at $\beta = .86$ or a once-fragmenting uranium nucleus at $\beta = .82$.

L. Alvarez and R. Hagstrom have found that P. Fowler's criticism of the emulsion method is invalid. Our recent velocity measurements of 110 cosmic rays with $Z > 50$ in emulsion support our claim that β is approximately equal to 0.5 and certainly lower than .65.

Tests of the reliability of the two independent layers of Cherenkov detectors are underway. Twenty-two pairs of Cherenkov spots for cosmic rays with $Z > 65$ and $\beta > .67$ have thus far been measured. The light from a uranium or curium is intense and should, at a very high confidence level, produce a detectable spot in at least one of the two Cherenkov detectors.

Present View of the Authors:

1. None of the tests and calibrations in progress requires us to retract our claim, even though it would have been wiser to publish only after their completion.

2. We do not wish to formally reiterate our claim now because our on-going stringent tests of the emulsion method and of the Cherenkov method will be complete in a few months.

3. With its high, nearly constant, Z/β and low β , the event is unique among those seen in balloons and satellites.

a. A mundane explanation--for example, a curium nucleus at $\beta = .86$ --is possible only if both the emulsion method and the Cherenkov method are discredited.

b. A monopole with strength $137 e$, velocity $\beta = 0.5$, and mass $>600 m_p$, is consistent with the data. The implied monopole flux is incompatible with a lunar search by L. Alvarez, R. Ross and P. Eberhard unless the monopole has some property that keeps them from being trapped.

c. A new particle with electron charge of $\sim 60 e$, with $\beta = 0.5$, and with mass $>2000 m_p$ is also consistent with the data and with previous negative searches for such hypothetical particles.

4. We cannot yet answer the question posed in the title. Nor can anyone else.

COMPARISON OF FRAGMENTING NUCLEI WITH MONOPOLE AND MASSIVE ELECTRICALLY CHARGED PARTICLE

Z	M (amu)	β	No. of frags.	Total prob. of occur. in some flight	Conf. level for fit to Lexan data ¹	Conf. level for fit to emul. data ²	Figure of Merit ³
76	192	.70	2	2×10^{-3}	3×10^{-6}	$<10^{-6}$	$<6 \times 10^{-11}$
79	197	.70	3	3×10^{-5}	10^{-5}	$<10^{-2}$	$<3 \times 10^{-12}$
81	205	.74	2	2×10^{-3}	3×10^{-3}	$<10^{-2}$	$<6 \times 10^{-9}$
83	209	.74	3	3×10^{-5}	10^{-2}	$<10^{-2}$	$<3 \times 10^{-9}$
92	238	.82	1	10^{-1}	10^{-1}	$<10^{-2}$	$<10^{-4}$
96	247	.86	0	1	10^{-1}	$<10^{-2}$	$<10^{-3}$
112	296	$>.98$	0	?	1	$<10^{-2}$	$<10^{-2}$
g/e = 137	>875	.5	0	Hypothetical Particles ?	1	~ 1	?
g/e = ~ 60	>2000	.5	0	?	1	~ 1	?

- 1) Based on F-test. χ^2 test gives ~ 10 times lower CL.
- 2) Based on meas. of halo radii for 110 nuclei with $Z > 50$ in emulsion.
- 3) Meas. of Cerenkov spots for 25 nuclei lower the fig. of merit for fast nuclei.