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NUCLEAR CHEMISTRY PROGRESS REPORT

Indiana University
Department of Chemistry and Cyclotron Facility

August, 1993

Prepared for the

U.S. Department of Energy

under grant

No. DE.FG02-88ER.40404.A000

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V.E. Viola and K. Kwiatkowski

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I. INTRODUCTION

During 1993, our program reached a major milestone with completion of the Indiana Silicon Sphere (ISiS) 4π charged-particle detector and inaugural tests of the device with beam. ISiS is designed for the study of energy dissipation and multifragmentation phenomena in light-ion-induced nuclear reactions at medium-to-high bombarding energies. Its primary characteristics include very low energy thresholds and large dynamic range ($0.4 \leq E/A \leq 96$ MeV), as well as good granularity (162 triple telescopes) and ejectile identification from Z = 1 to 20. The properties of the detector are described in the first entry to this report.

First tests of ISiS were conducted in May with a 200 MeV ^{4}He beam from the Indiana University Cyclotron. These studies demonstrated that the ion-chamber/silicon/CsI triple telescopes function as designed in the compact detector geometry of the device. In addition, the basic integrity of the vacuum, gas handling, electronics and data acquisition systems was confirmed. Subsequently, the device was completely dismantled, packed and transported to the Laboratoire National Saturne (LNS) in Saclay, France, where it was reassembled for a second test run with a 3.6 GeV ^{3}He beam in mid-July. Our group has not had a great deal of spare time during this period, which accounts for the abbreviated nature of this year's report.

The LNS test confirmed that we could operate our telescopes at angles as small as 14 deg and that our home-built computer-controlled multiple bias supplies worked satisfactorily. A new ethernet-based VME/CAMAC data acquisition system using XSYS software (designed by N. R. Yoder of IUCF) was implemented and operated with six CAMAC crates on line and a high data throughput. At the same time, a forward scintillator wall (ARCOLE) for detection of fast leading charged particles and a small-angle PPAC/silicon array for heavy recoil detection were added to the system.

The first full experiment with ISiS is scheduled at LNS during the October-November time period using beams of 1.8 and 3.6 GeV ^{3}He and 3.0 GeV protons incident on a ^{nat}Ag target (E228). The principal thrust of this experiment is to investigate multifragmentation processes in relatively simple systems where the excitation of subnucleonic degrees of freedom may play an important role in heating the system. The experiment involves a collaboration between our group, CEN Saclay (E. C. Pollacco, C. Volant and R.

Legrain) and Simon Fraser University (R. G. Korteling).

After the LNS experiment, ISiS will be repatriated to IUCF for studies near the Fermi energy with the cyclotron beams (200 q^2/A). The principal objectives of this research will be: (1) to investigate reaction dynamics for colliding systems above the Fermi energy, but where subnucleonic degrees of freedom are minimal--in order to improve the state of existing transport codes, and (2) to study nonequilibrium processes in such systems, especially IMFs emitted on a fast time scale and suprathermal protons at backward angles. Plans are also underway to develop a slow extraction beam line on the IUCF Cooler to extend these studies up to beam energies of 500 q^2/A MeV.

The '92-'93 contract period has also seen the completion of numerous earlier studies, as indicated later in this report; e.g. intranuclear cascade/expanding-emitting source calculations of multifragmentation in the 3.6 GeV ^3He + ^{nat}Ag system (collaboration with W. A. Friedman of the University of Wisconsin), the emission of IMFs from the neck region of highly excited fissioning nuclei; target N/Z effects on equilibrium and nonequilibrium IMF emission near the Fermi energy; light element nucleosynthesis/space radiation effects related to the ^{28}Si + ^4He reaction; and source size-lifetime properties as deduced from small-angle particle-particle correlations (collaboration with C. K. Gelbke, W. G. Lynch and M. B. Tsang at Michigan State University). Recent studies of Li, Be and B abundance in metal-deficient stars have also rekindled our interest in the relationship between galactic cosmic ray nucleosynthesis and the chemical evolution of the galaxy.

All of the research summarized here, as well as other activities of the group, are described in the following sections. Since information in these reports may be preliminary, unpublished results should not be quoted without consent of the authors.

II. RESEARCH

A. ISiS: THE INDIANA UNIVERSITY SILICON SPHERE, K. Kwiatkowski, D. S. Bracken, K. B. Morley, E. Renshaw, J. Brzychczyk, IU Chemistry Mechanical Instrument Shop, IU Chemistry Electronics Instrument Shop, T. Hamilton, IUCF Scintillator Laboratory, IUCF Wire Chamber Laboratory, N. Madden,[*] K.M. McDonald, J. Ottarson[§], C. Powell and V. E. Viola.

In order to investigate fragmentation processes in intermediate-to-high energy collisions, a versatile 4π nuclear particle detector array is required. Such an array must possess the following characteristics: (1) nuclide (Z and/or A identification) of products; (2) spatial characterization of the ejectiles with good granularity; (3) well-defined energy spectra; (4) low thresholds, and (5) easy, reliable energy calibrations. These have been the design goals for ISiS.

The ISiS detector (Fig. 1) is based on a spherical geometry and is designed primarily for the study of light-ion-induced reactions. It consists of 162 detector telescopes--90 in the forward hemisphere and 72 in the backward hemisphere--covering the angular ranges from 14° to 86.5° and 93.5° to 166°. The design consists of four rings, each composed of 18 tapered trapezoidal telescope housings, in both the forward and backward hemispheres. To increase granularity for the most forward angles, the ring nearest 0° is divided into two segments. A design drawing of the detector configuration in the forward hemisphere is shown in Fig. 2. Each telescope is composed of (1) a gas-ionization chamber (GIC) operated at 20-40 torr of CH_4 or 15-20 torr of C_3F_8; (2) a 500 μm ion-implanted passivated silicon detector, Si(IP), and (3) a 28 mm thick CsI(Tl) crystal with light guide and photodiode readout. Detectors are operated in a common gas volume; vacuum isolation is provided by a thin polypropylene window supported by a cage-like structure. The telescope dynamic range permits measurement of $Z \approx 1$-20 fragments with discrete charge resolution over the dynamic range $0.6 \leq E \leq 96$ MeV. The Si(IP)/CsI(Tl) telescopes also provide particle

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[*]Consultant, Livermore, California

[§]Consultant, NSCL, Michigan State University, East Lansing, MI 48824 identification for energetic H, He, Li and Be isotopes. The Si(IP) detectors constitute a critical component of ISiS in that they provide both excellent energy resolution and reliable energy calibration for the GIC and CsI(Tl) elements. A photo of the detector with the forward hemisphere loaded is shown in Fig. 3.

The ISiS detector solid angle/energy acceptance is significantly improved compared to currently operating 4π arrays based on phoswich technology. The figure of merit here is the product of solid angle coverage and the fraction of the total fragment energy spectra that is above threshold. For ISiS, the total solid angle is 85% of 4π, as determined by simulations with the GEANT code. The major acceptance advantage of the ISiS array is its very low detector thresholds ($E/A \approx 0.5$ MeV compared to $E/A \approx 2.0$-3.5 MeV for phoswich telescopes). Due to the distortions of the fragment spectra toward low energies for light-ion-induced reactions above about 500 MeV/nucleon, the relative gain in differential cross section is substantial ($\geq$ a factor of three) for the $^{3}He + {}^{nat}Ag$ system which we have been studying.

During the past year, a large number of tasks were completed to make ISiS operational. These included: (1) design and construction of the dual gas-handling system and vacuum controls; (2) production of vacuum electrical feed-throughs for our 462 detectors; (3) continued work with Phillips Scientific on developing their 7164H fast, peak-sensing ADCs; (4) solving problems with the charging of our passivated silicon detectors (see entry II.E.); (5) constructing and testing 500 channels of our IU-built quint preamp/shaper modules; (6) designing and fabricating signal cables; (7) testing constant fraction discriminators and noise reduction efforts to achieve very low thresholds; (8) designing, building, testing and developing control software for our IU-developed CAMAC-controlled bias supply and leakage current monitoring system; (9) developing the software for the data acquisition system using a new ethernet-based VME/CAMAC system and XSYS software; (10) fabricating very thin, conducting windows (~ 200 $\mu g/cm^2$ polypropylene) to isolate the beam vacuum from the gas-ionization chambers, and finally (11) integrating all these components into a working system.

First tests of ISiS with the forward 2π detector array fully loaded were conducted at IUCF in May, 1993 with 200 MeV ^{4}He ions incident on an Al target and at the Laboratoire National Saturne in July, 1993 with 3.6 GeV ^{3}He ions bombarding a ^{nat}Ag target. This provided the first opportunity to test the integrated system--vacuum, gas handling, detectors, electronics and data acquisition under run conditions.

A critical feature of the ISiS design is the separation between the beam-line vacuum and the common gas volume in each hemisphere required for operation of the hemispheres. This isolation is provided by a birdcage-like structure, the ribs of which are geometrically coincident with the trapezoidal detector housings, covered by a continuous sheet of 180-400 $\mu g/cm^2$ stretched polypropylene. The polypropylene is sprayed with a thin layer of colloidal graphite to provide electrical grounding for operation of the ion chambers. The vacuum/gas system worked very successfully over a long term (several days), providing vacuum of $\sim 5 \times 10^{-5}$ torr in the beam line with 20 - 25 torr of CF_4 in the detector.

The ability of the new CAMAC-controlled detector bias supply developed at IU proved successful in applying bias and monitoring leakage currents during the LNS tests. Both hardware and software for the computer-controlled bias supplies constructed at Indiana University functioned as designed. In addition, our quint preamp/shaper modules, also built locally, performed very reliably, providing very low noise and excellent energy resolution for all detectors, as well as fast signal rise times of the order of 20 ns for the silicons. Sample spectra from about 30 minutes of beam on one series of detectors from the array (corresponding to Fig. 2) are shown in Fig. 4. Gas pressure in the ion chambers was 20 torr of CF_4 operating over a 3 cm detector length. The LNS tests confirmed that we could operate our detectors as close as 14° to the beam and that we could identify protons up to 95 MeV (ΔE in the silicons $\cong$ 0.5 MeV). which imposes the most severe test of our ability to achieve low-energy thresholds.

The VME-based data acquisition system with a 25 MHz Motorola MVME167 CPU was implemented successfully using ethernet during these tests. At LNS, the system controlled six CAMAC crates, with events for ISiS, beam monitoring, and the Arcole scintillator wall for fast leading particles.

The first fall production run with ISiS is scheduled to occur at LNS during October-November, 1993.

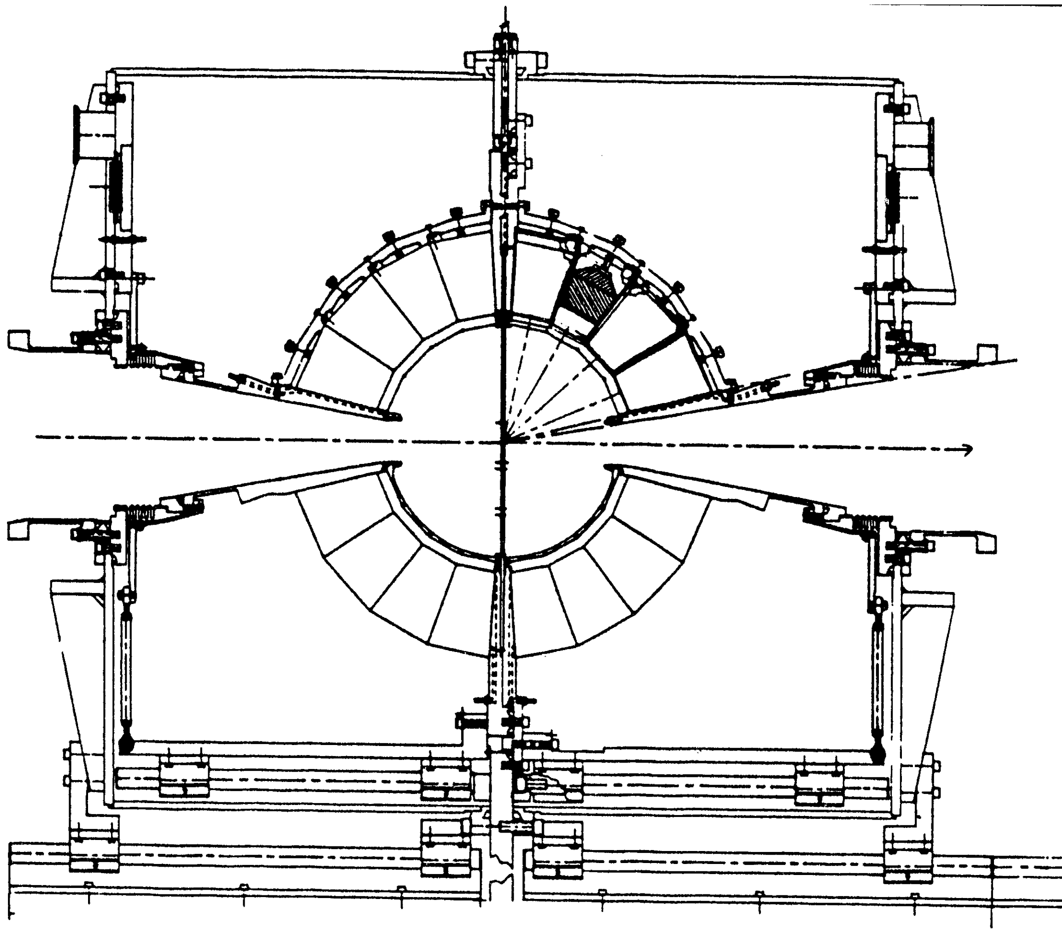

Figure 1. Engineering drawing of ISIS.

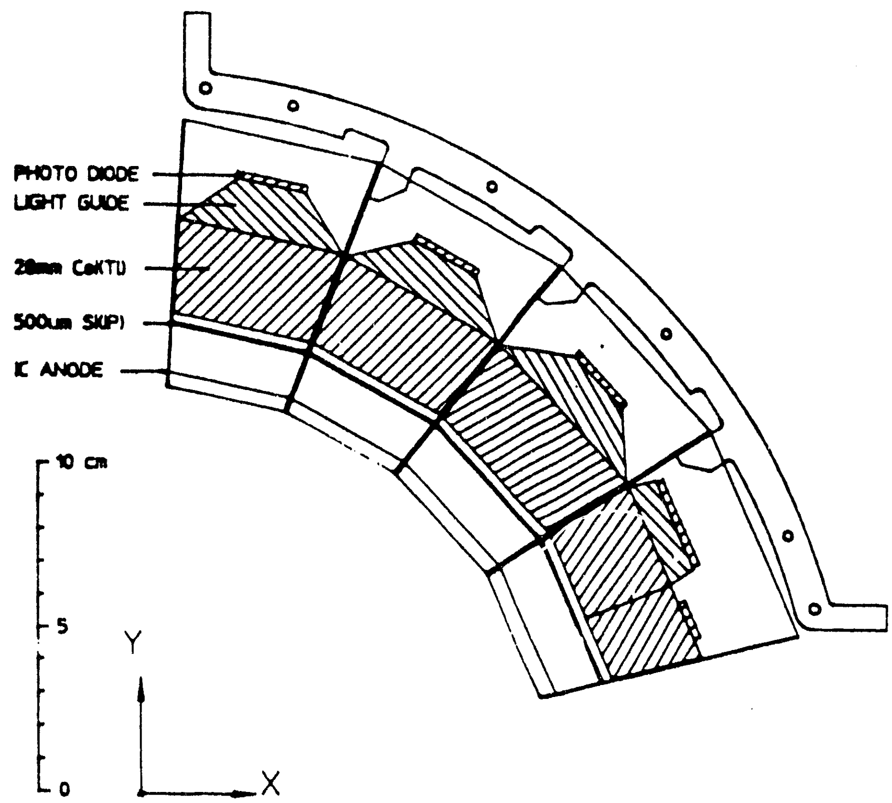

Figure 2. Telescope configuration for forward hemisphere array. Each unit is part of an 18-member ring; forward-most element is segmented into two halves.

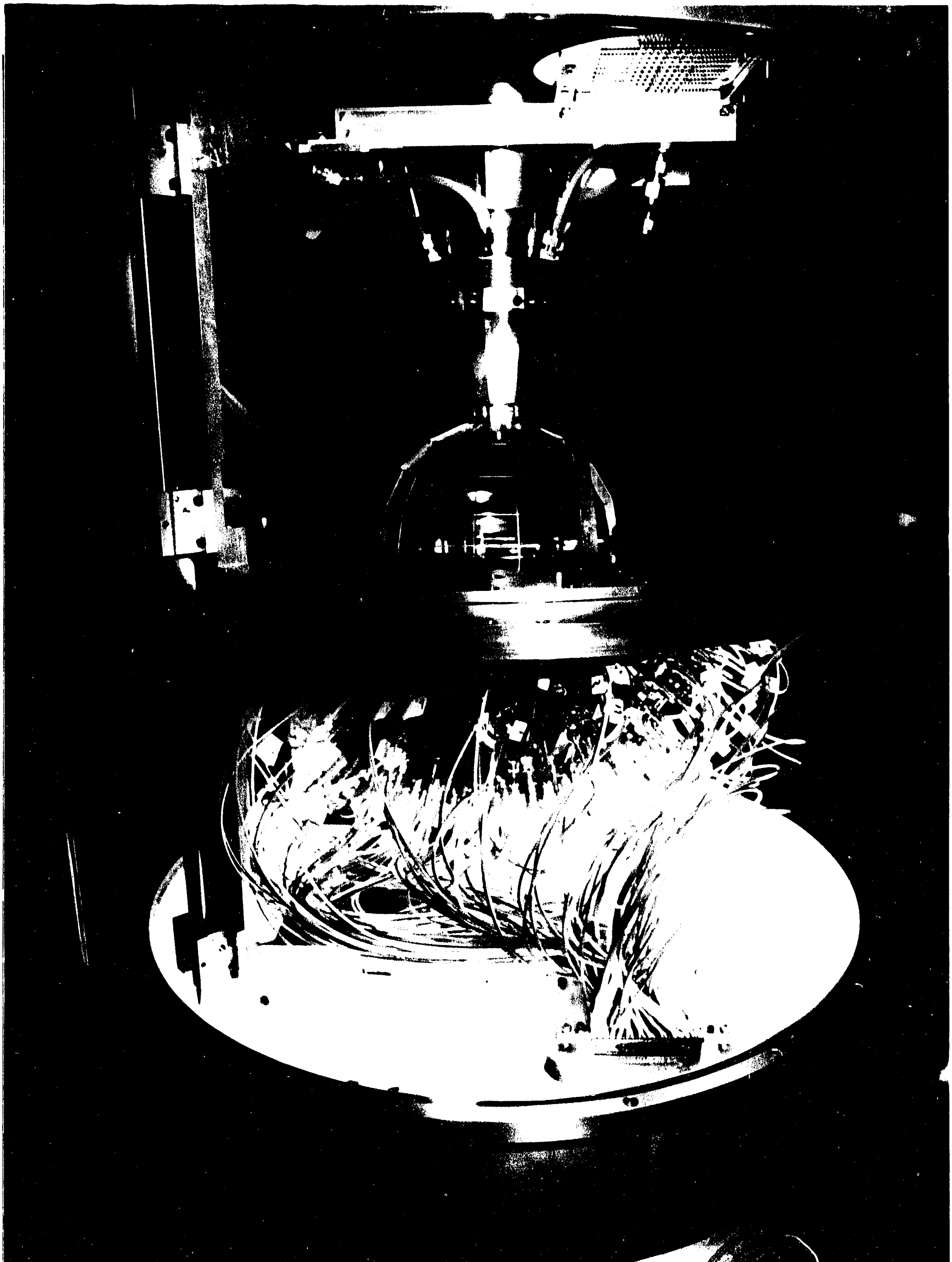

Figure 2

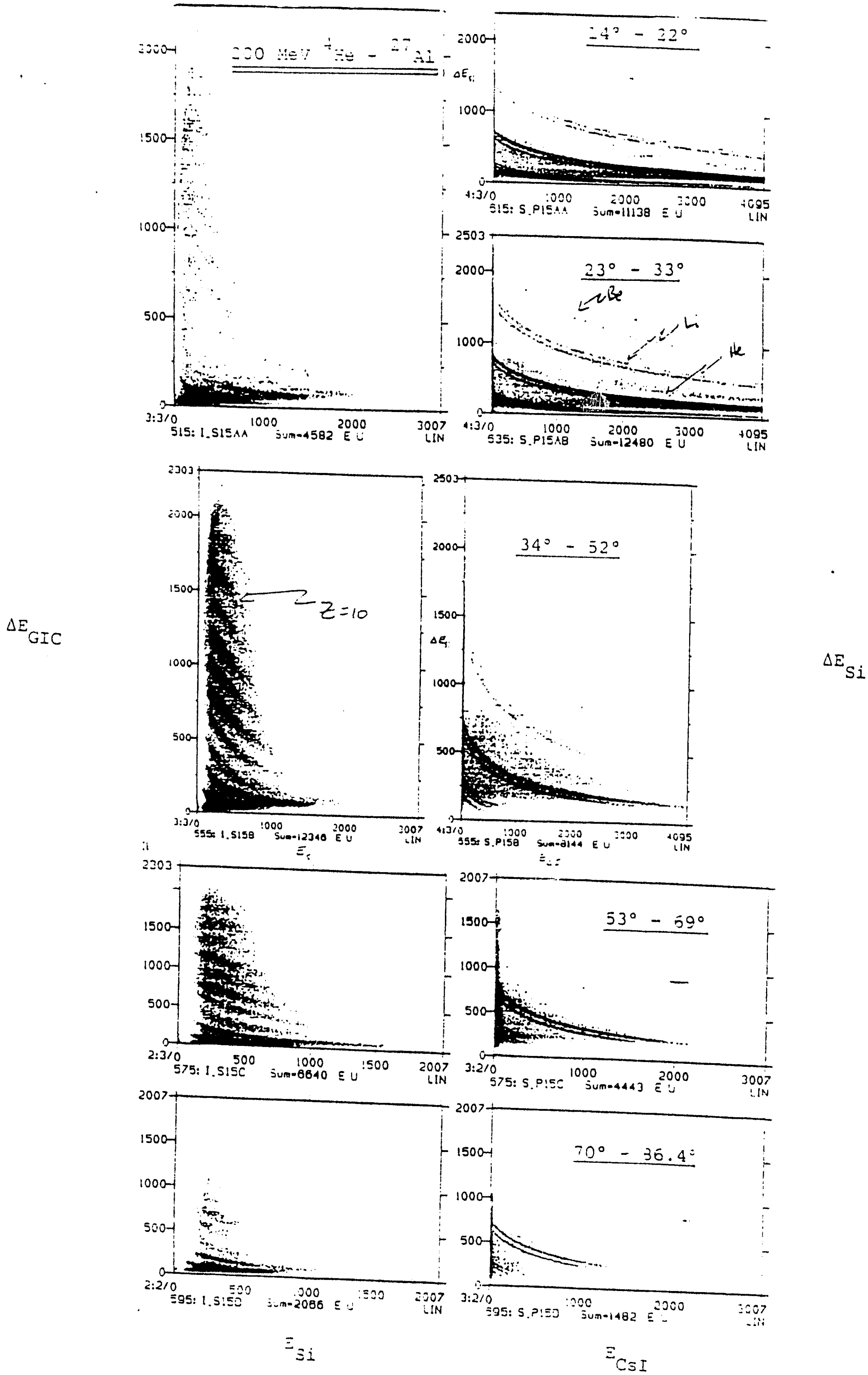

Figure 4. First ISiS beam on target, May 1993. Particle identification spectra for a slice of forward hemisphere detectors corresponding to Figs. 1 and 2.

B. ENERGY DISSIPATION AND MULTIFRAGMENTATION DECAY IN LIGHT-ION-INDUCED REACTIONS, K. Kwiatkowski, L. W. Woo, V. E. Viola, W. A. Friedman**, E. C. Pollacco‡ and C. Volant,§§ and S. J. Yennello***.

Multifragment emission data from the ^{3}He + Ag reaction at 3.6 GeV (Ref. 1) have been examined in the framework of a hybrid model that treats the reaction dynamics in terms of an intranuclear cascade calculation,[2] followed by decay from an expanding, emitting source.[3]

The INC calculations demonstrate that the average excitation of the excited residues formed in central collisions increases rapidly with bombarding energy; for more peripheral collisions this increase is much more gradual. The important role of the Δ resonance in producing highly excited residues is illustrated by the calculations. This mechanism provides a rapid, efficient means of energy dissipation that would appear to be essential in forming the highly excited species required for multifragmentation in light-ion-induced reactions. The results suggest that multifragmentation studies, when complemented by pion emission probabilities, may provide valuable insight into the question of pion reabsorption in the nuclear medium.[4] The INC calculations also show that $p_{\|}$ and $p_{\perp}$ are comparable for excitation energies above about 500 MeV; these calculated values are in good agreement with source velocities derived from a rapidity analysis of the spectra for high multiplicity events in the ^{3}He + Ag system.

Fits to the 3.6-GeV ^{3}He + Ag multiplicity data with the combined INC/EES model require a relatively soft equation of state (K = 144). This value also described the charge distribution data best. Calculations with stiffer equations of state or without Δ excitations in the cascade severely underpredict the high mulitplicity data; in fact, the calculations are quite sensitive to all parameters. In order to describe the data with a stiffer equation of state, the probability for Δ excitation and/or pion absorption in the INC code would need to be increased significantly in order to enhance the probability for high excitation energy residues. The importance of employing a realistic excitation energy distribution in multifragmentation calculations is also stressed by this work. If the EES calculations are performed with the average INC excitation energy instead of the full distribution, the data are significantly underpredicted. Comparison of the INC/EES calculations with experimental kinetic energy spectra accounts for the major features of the data as shown in Fig. 1. The calculations successfully predict changes in IMF spectral shapes for bombarding energies below and above about 1 GeV, i.e., broadening of the Coulomb peaks toward

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lower energies and flattening of the spectral tails at high projectile energies, as observed in the data.[1] In the context of the EES model, this behavior is explained in terms of energetic IMFs being emitted early in the expansion, where the expansion velocity is large, and low energy IMFs being emitted from nuclear matter at low density. While the quantitative agreement with the spectra is not perfect, the qualitative features of the data are successfully described.

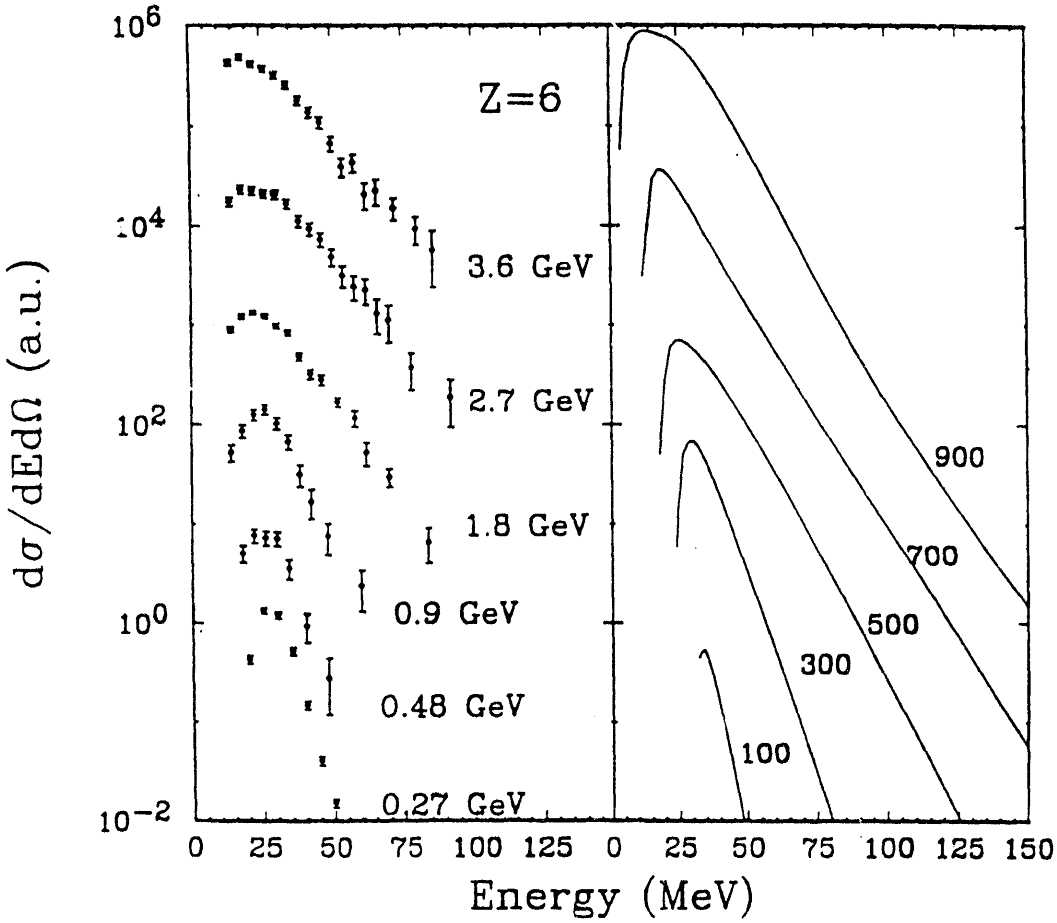

Figure 1. Left frame: inclusive spectra for C fragments at backward angles for $^{3}He+^{nat}Ag$ reaction (Ref. 1) as several bombarding energies. Right frame: Spectral shapes predicted by EES model for emission of Z=6 fragments at 117° for several residue excitation energies, as indicated on figure.

It is also of interest to compare the charge distributions predicted by the INC/EES model with the experimental data. In Fig. 2, we present such a comparison with a calculation which employs the standard (with Δ) INC code with the EES model for various values of the compressibility parameter K. The calculation is quite sensitive to the value of K; a value of K = 144 gives the best fit to the data. Thus, the results for the charge distributions are self-consistent with other observables.

These INC-EES calculations provide a physically transparent framework for understanding the basic features of light-ion-induced multifragmentation reactions. The fundamental roles of inelastic N-N scattering and expansion of the nuclear medium are essential in confrontation of this model with the data.

1. S.J. Yennello, *et al.*, Phys. Rev. Lett. **67**, 671 (1991); Phys. Lett. B **246**, 26 (1990).
2. Y. Yariv and Z. Fraenkel, Phys. Rev. C **20**, 2227 (1979); ibid, **26**, 2138 (1982).
3. W.A. Friedman, Phys. Rev. **42**, 667 (1990).
4. J. Cugnon and M.C. Lemaire, Nucl. Phys. A **489**, 781 (1988).

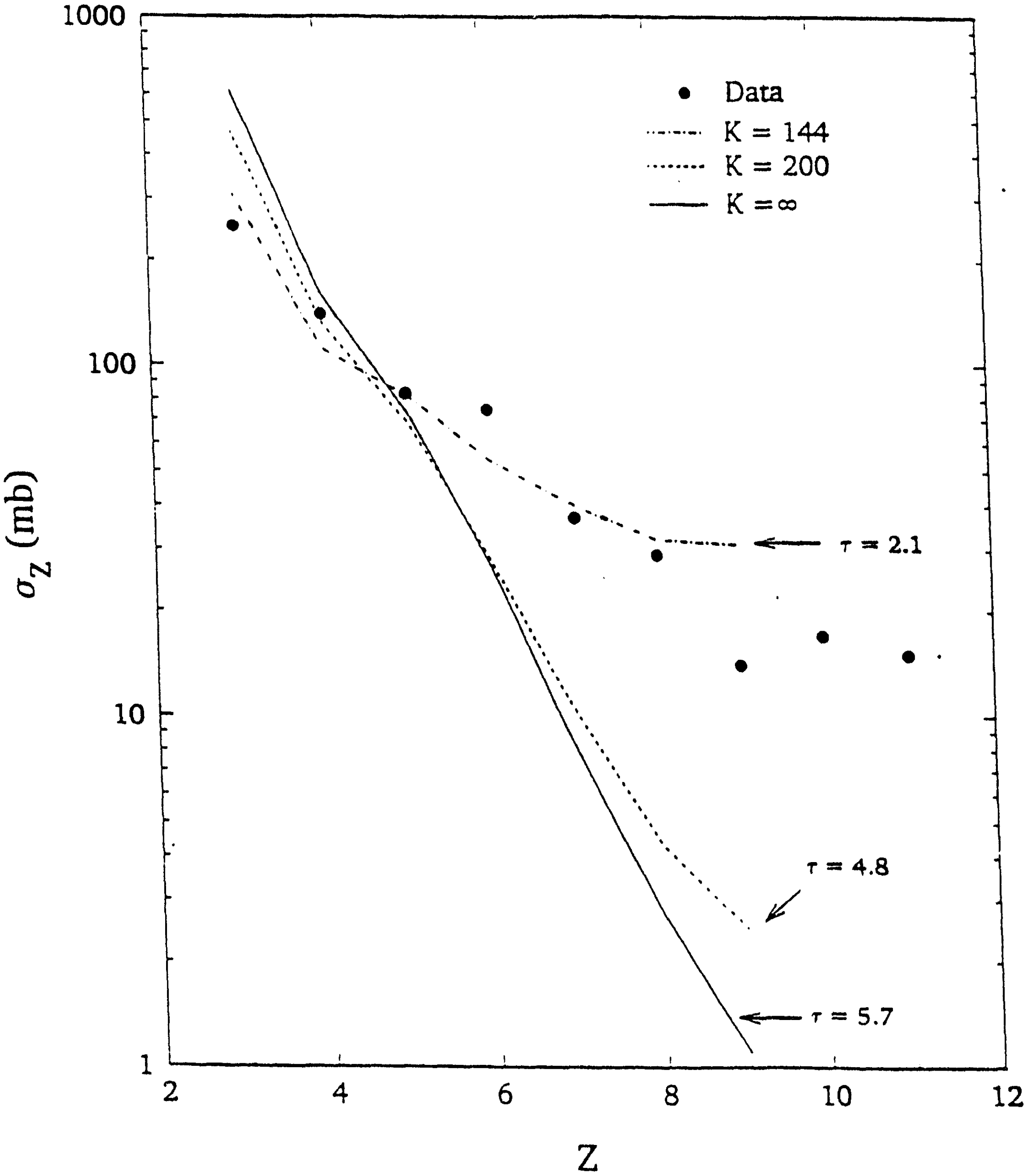

Figure 2. Experimental inclusive charge distribution for 3.6-GeV ^{3}He+^{nat}Ag reaction (points) compared with predictions of INC/EES model for K=144, K=200 and K=∞.

C. CALCULATIONS OF ISOTOPIC IMF YIELDS IN THE ^{4}He + ^{116,124}Sn REACTION, J. Brzychczyk, D. S. Bracken, K. Kwiatkowski, K. B. Morley, E. Renshaw and V. E. Viola.

The effect of target N/Z ratio on the properties of intermediate-mass fragment (IMF) ejectiles has been investigated in the reaction of E/A≈50 MeV ^{4}He ions with targets of ^{116}Sn and ^{124}Sn. Both equilibrium-like and nonequilibrium sources have been studied by performing measurements at extreme backward and forward angles.

The data demonstrate the influence of target composition on both the charge and isotopic distributions of the fragments. Elemental cross sections from the ^{4}He + ^{116}Sn system are distinctly enhanced relative to ^{4}He + ^{124}Sn. For nonequilibrium emission, both targets produce similar yields for light IMFs; however, the ratio of the elemental cross sections from ^{116}Sn to those from ^{124}Sn becomes increasingly larger as a function of increasing fragment charge.

The backward-angle emission of IMFs can be interpreted in terms of statistical emission from a compound nucleus.[1] In order to examine the influence of neutron binding energies and angular momentum on the ^{116,124}Sn charge distributions, we have performed calculations with the evaporation code BUSCO.[2] These results are shown in Fig. 1. Using a value of L=19$\hbar$ and the maximum available excitation energy, the cross sections for the ^{116}Sn target are relatively well reproduced. For the ^{124}Sn target the calculation successfully predicts the lower IMF cross sections relative to ^{116}Sn, but is much less successful in describing the heaviest fragment yields. In both cases the slope of the calculation is steeper than the data. By increasing the input angular momentum to L=22$\hbar$, a somewhat better fit to the ^{124}Sn data is obtained, both in magnitude and slope. A possible explanation for this result is that the L-wave distribution for the average emitting system formed in the ^{4}He + ^{116}Sn reaction may sample a higher range of angular momentum values than in ^{4}He + ^{116}Sn reactions, a result consistent with the increased decay widths for neutron emission from the neutron-excess system. Nonetheless, the BUSCO calculation underpredicts heavy fragment yields, especially for the neutron-excess targets. This suggests that calculations of Γ_n/Γ_{IMF} in this code may need some modification.

While the backward angle emission of IMFs can be understood relatively well in terms of the decay of a compound nucleus, the mechanism of nonequilibrium production is still poorly understood. For these ejectiles the important question of the time scales complicates the theoretical interpretation of the data. The accreting source model[3] is based on the assumption of local statistical emission from an excited subsystem of the nucleus created by the fusion of the projectile with some number of target nucleons. This source simultaneously emits fragments and cools by accreting nucleons from the remainder of the target. In our calculations we have assumed an initial source size of eight nucleons, an accretion rate of 2 nucleons/fm/c, and an exit-channel Coulomb barrier of 0.9 times the touching-spheres value. The Fermi energy of 24 MeV and normalization coefficients were

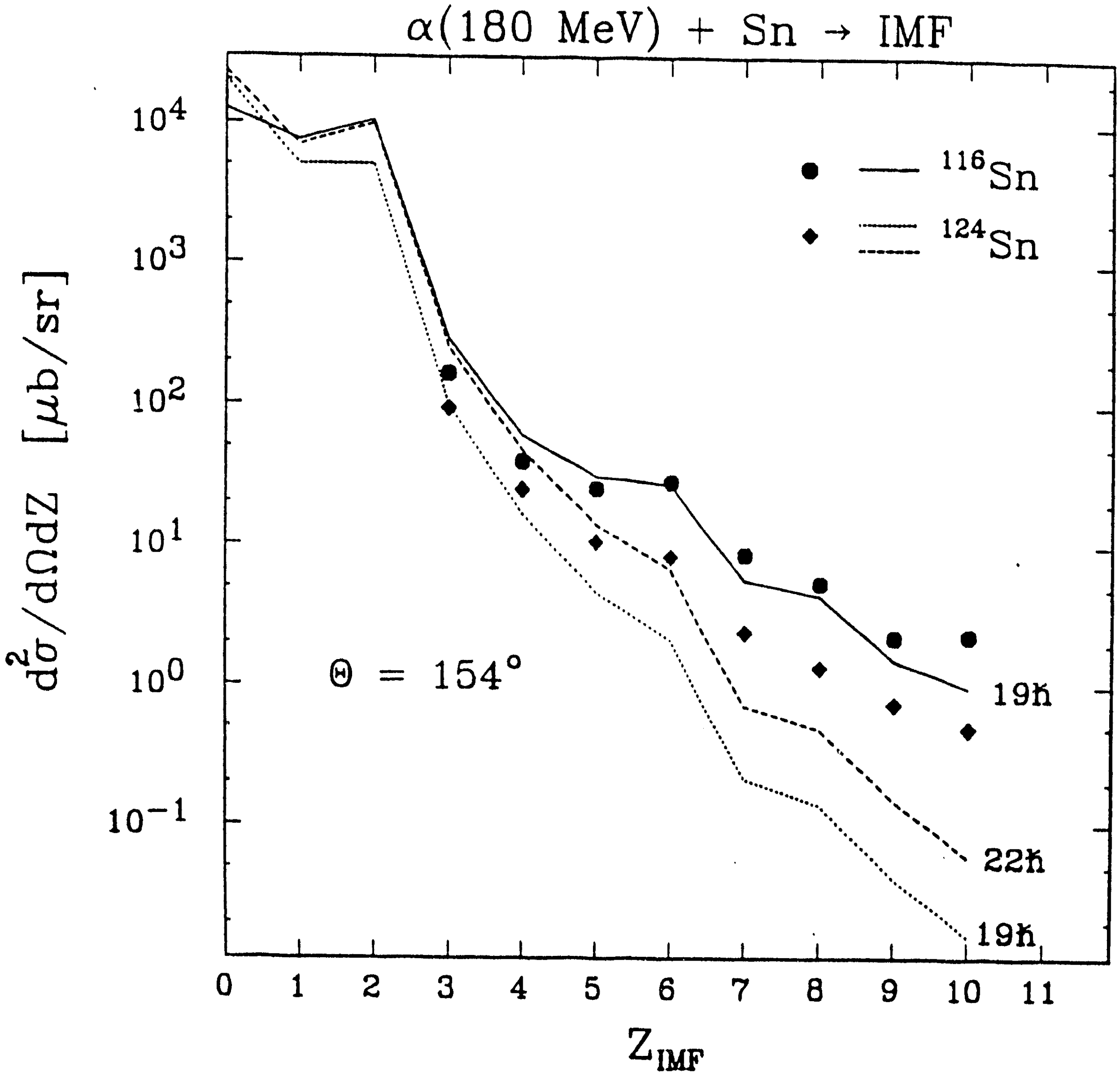

Figure 1. Charge distributions for IMFs emitted at 154° for 180 MeV $^4He+^{116,124}Sn$ reactions, compared with BUSCO[2] calculations. Calculations are performed for L=19ℏ for both systems and L=22ℏ for ^{124}Sn .

fixed by requiring a fit to the charge distributions.

The isotopic yield results are shown in Fig. 2. We observe general agreement with the data, including ^{7}Be. The ratios $\sigma(^{116}Sn)/\sigma(^{124}Sn)$ are also reasonably well reproduced by the calculations. Emission temperatures calculated with the model are lower for heavier fragments and somewhat higher in the case of the ^{124}Sn target.

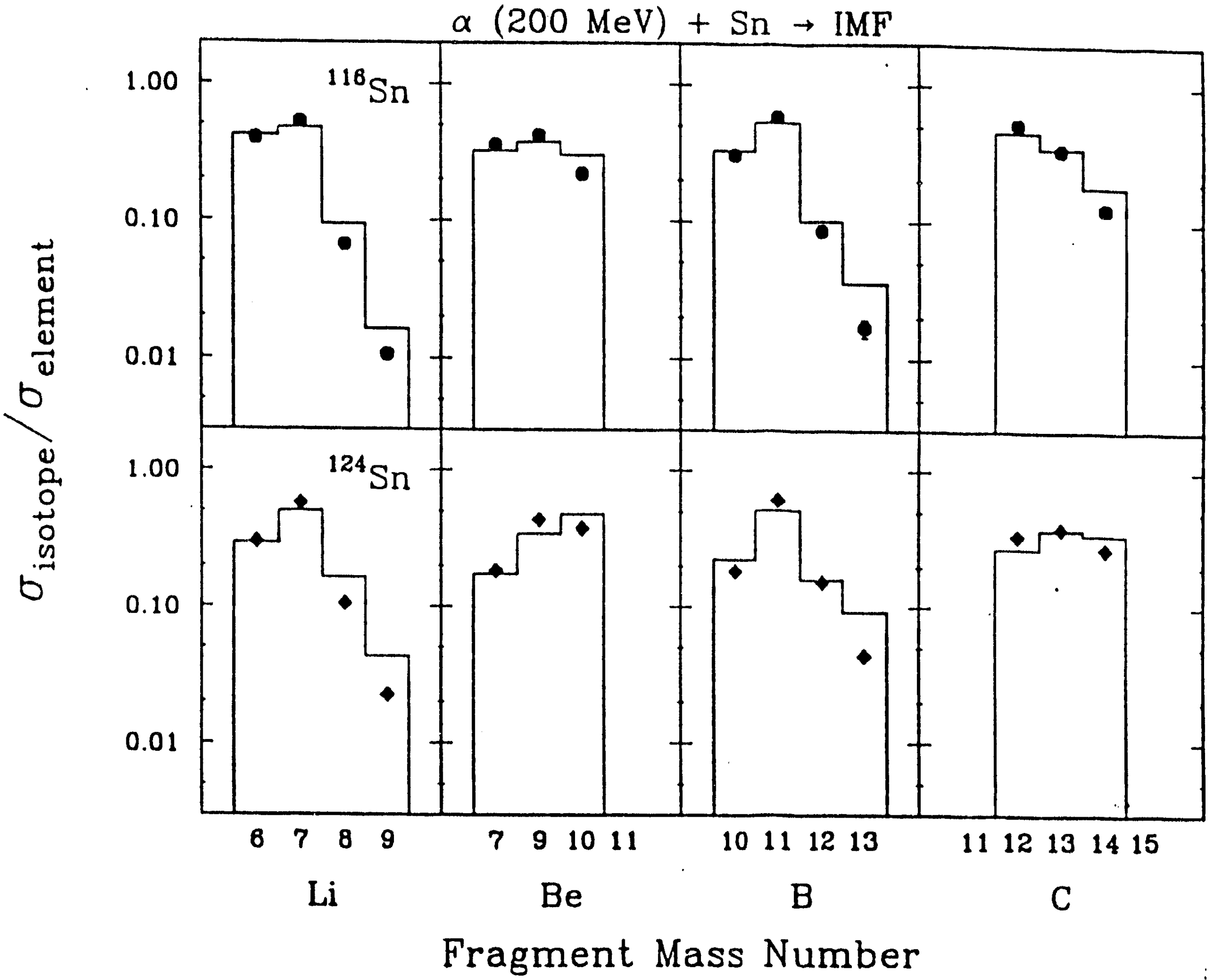

Figure 2. Isotopic ratios for Li, Be, B and C fragments, for ^{116}Sn (upper) and ^{124}Sn (lower) targets. The solid line is the prediction of the accreting source model.[3]

Whereas the calculation reproduces the total cross sections well, it fails to reproduce the angular distributions. The predicted angular distributions are much flatter than the experimental ones. Also, the slopes of the energy spectra for the lighter fragments are too steep. For the heavier fragments, the spectral shapes are well-reproduced, although the absolute cross sections are too small at forward angles. Somewhat more rapidly decreasing angular distributions can be obtained by using a lower value of the accretion rate. The charge and isotopic distributions, as well as energy spectra, are relatively insensitive to such a change. To obtain flatter energy spectra, however, it is necessary to increase the Fermi energy, which in turn causes the charge and isotopic distributions to become flatter. Thus, the accreting source model describes many features of these data satisfactorily, although complete self-consistency cannot be achieved for all observables.

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1. V.E. Viola and K. Kwiatkowski, *Proc. of Symposium: Towards a Unified Picture of Nuclear Dynamics*, edited by S.M. Lee and F. Sakata (AIP Conf. Proc. No. 250, New York, 1991).
2. J. Gomez de Campo, Phys. Rev. Lett. **61**, 290 (1988).
3. W.A. Friedman and W.G. Lynch, Phys. Rev. C **28**, 16 (1983); ibid., **28**, 950 (1983); D.J. Fields, W.G. Lynch, C.B. Chitwood, C.K. Gelbke, M.B. Tsang, H. Utsonomiya and J. Aichelin, Phys. Rev. C, **30**, 1912 (1984).

D. CROSS SECTIONS FOR A = 6 - 30 FRAGMENTS FROM THE ^{4}He + ^{28}Si REACTION AT 117 AND 198 MeV, L. W. Woo,* K. Kwiatkowski, W. G. Wilson,† V. E. Viola, H. Breuer,§§§ and G. J. Mathews.****

We have measured inclusive data for mass, kinetic energy and angular distributions from the ^{4}He + ^{28}Si reaction at 117.4 and 198.5 MeV, or $E/A = 29$ and 50 MeV/nucleon. An understanding of such intermediate-energy light-ion interactions is important to studies of cosmic-ray related phenomena associated with space-radiation effects and nuclear astrophysics.

Cosmic-ray nuclei represent an important source of bit upset generation in microelectronic devices. An essential ingredient for any attempt to account for these radiation-induced errors is the availability of reliable doubly differential cross-section information, $d^2\sigma/d\Omega dE$, for cosmic-ray-induced reactions in the material of interest, primarily silicon and oxygen. Of particular concern in evaluating radiation effects is the possibility that energetic heavy recoil fragments may enhance the magnitude of radiation effects due to their high ionization density, proportional to AZ^2 of the fragment. The large excess of energetic heavy fragments at forward angles (relative to theoretical predictions) observed in these studies, as well as for the p+^{27}Al system,[1] indicate that heavy recoils may be a significant contributor to error generation in silicon chips exposed to cosmic-ray fluxes.

Three problems of astrophysical interest are also addressed by these data. The first relates to the origin of galactic cosmic rays (GCR). Measurements[2] of the isotopic composition of galactic cosmic rays reveal a significant enrichment of neutron-excess Ne and Mg isotopes relative to their interstellar medium (ISM) ratios. This observation suggests that GCR progation may be associated with an r-process-like environment. However, in order to test such theories, it is essential to understand the modification to the primary source flux due to nuclear reactions which occur during transport through the interstellar medium. Corrections for these processes depend on an accurate knowledge of cross sections for reactions between heavy cosmic-ray primaries (such as ^{28}Si) with hydrogen and helium (the dominant components of the interstellar medium).

In Table I isotopic ratios for the stable Ne and Mg isotopes are compared with the cross-section ratios for these data and for the 180-MeV p+^{27}Al reaction.[1] The data demonstrate that in these spallation processes, mass numbers $A = 24 - 26$ (Mg isotopes on a cosmic-ray time scale, except for ^{26}Al) and $A = 20 - 22$ (Ne isotopes) are populated with roughly equal probability. Thus one would expect enrichment of neutron-excess species relative to solar system abundances in the spectrum of neon and magnesium isotopes formed in the spallation of Si primaries in the cosmic-ray flux. Similarly, for mass numbers

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$A = 16 - 18$ (oxygen) enhanced production is observed for the neutron-excess isotopes; however, at this level contributions from the spallation of ^{20}Ne and ^{24}Mg primaries also becomes important. Thus, the observation of enriched ratios for neutron excess isotopes in the cosmic-ray flux relative to solar system material is at least in part a consequence of spallation reactions experienced by any primary flux in passing through the interstellar medium. Quantitative evidence for anomalies in the cosmic-ray isotopic composition can only be understood after correction for these spallative processes.

A second similar application of these data relates to the abundances of secondary nuclei produced in meteorites by GCR-induced spallation reactions during the meteorite lifetime. These measured cross sections, in conjunction with isotope ratios observed for a given meteorite, can be used to infer information on its exposure geometry and the history of GCR fluxes.

A third astrophysical problem of related interest is the nucleosynthesis of the elements lithium, berylium, and boron (LiBeB). The abundances of the nuclides ^{6}Li, ^{9}Be, ^{10}B, and ^{11}B can be understood as primarily due to reactions of galactic-cosmic-ray H and He with He and CNO nuclei in the interstellar medium (CNO = carbon, nitrogen, and oxygen).[3] One open question concerning this model is the possible contribution of heavier target species in the interstellar medium (e.g., Ne, Mg, and Si spallation) to the production of LiBeB. Since the relative abundances of these target-source elements are smaller than for CNO (C/N/O/Ne/Mg/Si = 0.61/0.13/1.00/0.14/0.06/0.06), the heavier species can only be important if the formation cross sections for LiBeB are significantly higher than for CNO. The cross-section results for LiBeB listed in Table I are slightly lower for Si than for CNO targets[4] at these energies. This suggests that the high energy cross sections for ^{20}Ne and ^{24}Mg, the other two major contributors to GCR synthesis of LiBeB, are comparable. Inclusion of these ^{4}He+^{28}Si results and those of Ref. 1 into the GCR calculations of Walker, *et al.*,[3] serves to increase the absolute production rates of ^{6,7}Li, ^{7}Be, and ^{10,11}B by about 2-4% and to have little effect on the isotope ratios. Thus, the contribution of species heavier than CNO to the LiBeB formation in galactic cosmic-ray interactions with the interstellar medium appears to be small and does not significantly perturb the existing scenario for LiBeB nucleosynthesis.

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1. K. Kwiatkowski, S.H. Zhou, T.E. Ward, V.E. Viola, H. Breuer, G.J. Mathews, A.C. Mignerey, and A. Gökmen, Phys. Rev. Lett. **50**, 1648 (1983).
2. M.E. Weidenbeck and D.E. Greiner, Phys. Rev. Lett. **46**, 682 (1981).
3. T.P. Walker, G.J. Mathew, and V.E. Viola, Astrophys. J. **229**, 745 (1985).
4. S.M. Read and V.E. Viola, At. Data Nucl. Data Tables **31**, 359 (1984).

TABLE I.

Isotope number ratios of neon and magnesium isotopes in ISM and GCR[2] compared with cross section ratios for corresponding mass numbers in the p+^{27}Al reaction[1] and these data.

	^{20}Ne : ^{21}Ne : ^{22}Ne	^{24}Mg : ^{25}Mg : ^{26}Mg
ISM	1.0 : 0.024 : 0.073	1.0 : 0.13 : 0.14
GCR	1.0 : 0.25 : 0.67	1.0 : 0.28 : 0.30
180 MeV p + ^{27}Al	1.0 : 1.12 : 1.03	1.0 : 1.13 : 1.40
198.5 MeV ^{4}He + ^{28}Si	1.0 : 0.55 : 1.50	1.0 : 0.94 : 0.85

E. CHARGING EFFECTS OF PASSIVATED SILICON DETECTORS, K. B. Morley, D. S. Bracken, K. Kwiatkowski, E. Renshaw, K. McDonald and V. E. Viola.

During tests of prototype telescope assemblies for the Indiana Silicon Sphere, an unusual charging effect was observed in the passivated silicon detectors when operated in gas for periods of time exceeding 10 minutes. This effect was not observed earlier with standard 5 cm x 5 cm passivated silicon detectors operated under identical conditions. The effect mimics the radiation-damage response common to silicon devices when exposed to large fluxes of heavily ionizing radiation; i.e. there is a gradual increase in leakage current as a function of time, eventually leading to runaway conditions whereby the device becomes unusable. However, the effect does not appear to be not permanent and can usually be reversed with proper treatment.

Specific conditions which precipitate this effect are: (1) positive bias applied to the front face (p^+) of the detector; (2) operation in gas at 10 torr or higher--CF_4, C_3F_8, isobutane and argon all behave similarly, and (3) presence of a source of ionizing radiation; e.g. beam on target or an alpha particle source. Tests with a 0.1 μ Ci ^{241}Am source yield the behavior shown in Fig. 1. The increase in leakage current with time appears only when all three of the above conditions are met. Removal of the source and/or the gas causes the increase to stop, as shown. Some of our detectors operate with negative bias; the effect was not observed in any of these devices.

This charging effect can be eliminated by placing a mask over the passivated silicon oxide layer of the detector. The solution suggests a mechanism whereby secondary electrons are collected on the passivated silicon surface and through charge buildup, eventually create a current path to the active silicon. Detectors can usually be restored by cleaning with semiconductor grade solvents and placing them under bias in vacuum for extended periods of time. Another preventative treatment was long-term exposure to H_2 gas at elevated temperatures.

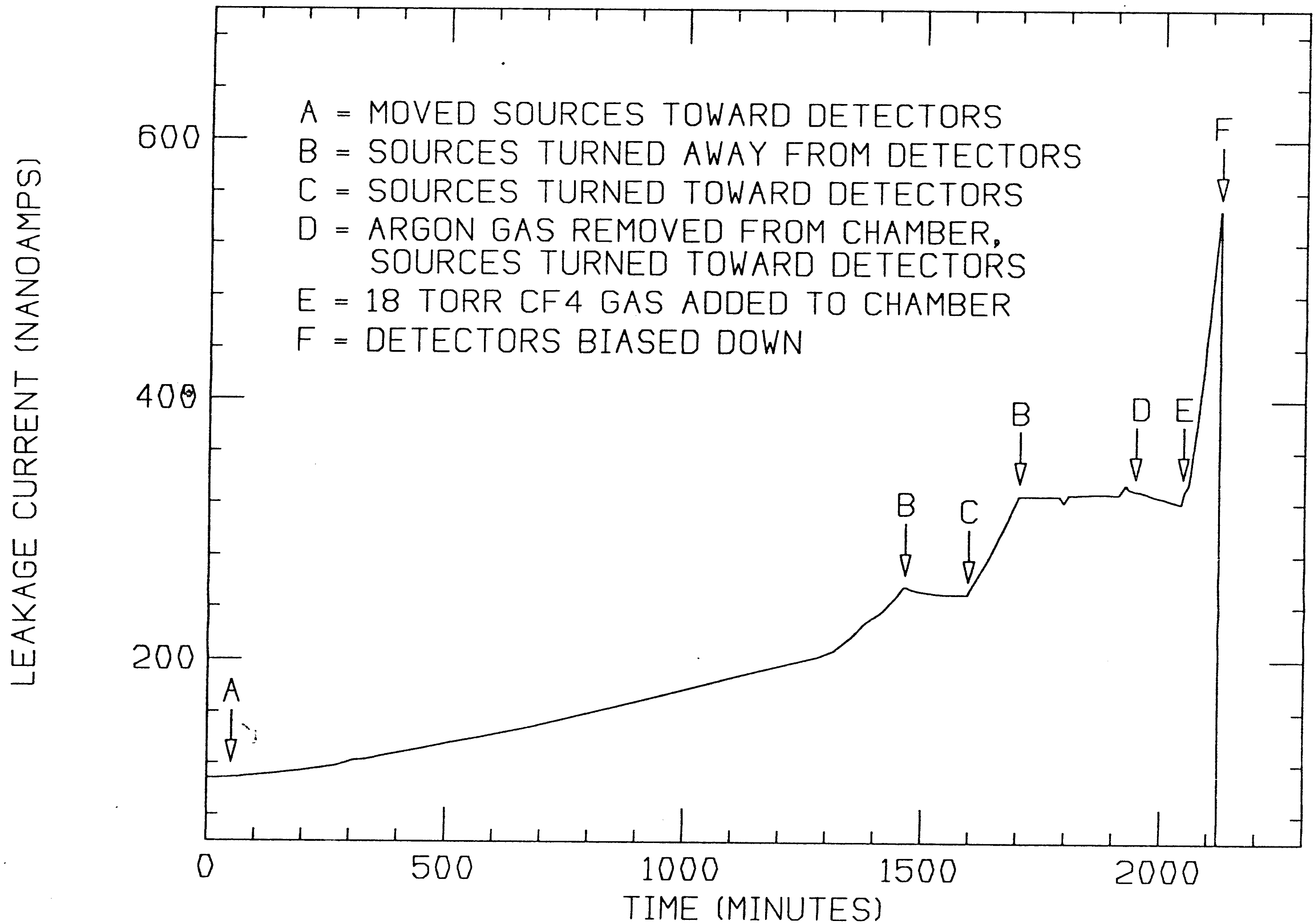

Figure 1. Leakage current as a function of time for various detector conditions.

III. INDIANA UNIVERSITY PERSONNEL

Faculty and Professional Research Staff

V. E. Viola, Professor of Chemistry
K. Kwiatkowski, Senior Scientist
J. Brzychczyk, Research Associate[a]

Graduate Students

D. S. Bracken, Department of Chemistry
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T. Hamilton, Department of Chemistry
K.M. McDonald, Department of Chemistry
K. B. Morley, Department of Physics[a]
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Other Personnel

K. Blackwell, Secretary
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C. Powell, Undergraduate assistant (Chemistry)[a,d]

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IV. PUBLICATIONS AND ACTIVITIES (8/1/92 to 7/31/93)

A. Articles in Refereed Journals

1. Emission of IMFs Normal to the Fission Axis in Hot Heavy Nuclei, D. E. Fields, K. Kwiatkowski, K. B. Morley, E. Renshaw, J. L. Wile, S. J. Yennello, V. E. Viola and R. G. Korteling, Phys. Rev. Lett. 69, 3713 (1992).

2. Cross Sections for A = 6-30 Fragments from the $^{4}He + ^{28}Si$ Reaction at 117 and 198 MeV, L. W. Woo, K. Kwiatkowski, W. G. Wilson, V. E. Viola, H. Breuer and G. J. Mathews, Phys. Rev. C 47, 267 (1993).

3. Isotopic Yields of IMFs Emitted in the E/A = 50 MeV $^{4}He + ^{116,124}Sn$ Reactions, J. Brzychczyk, D. S. Bracken, K. Kwiatkowski, K. B. Morley, E. Renshaw and V. E. Viola, Phys. Rev. C 47, 1553 (1993).

4. Two-deuteron Correlation Functions in $^{14}N + ^{27}Al$ Collisions at E/A = 75 MeV, W. G. Gong, P. Danielwicz, C. K. Gelbke, N. Carlin, R. T. de Souza, Y. D. Kim, W. G. Lynch, T. Murakami, G. Poggi, M. B. Tsang, H. M. Xu, S. Pratt, K. Kwiatkowski, V. E. Viola, S. J. Yennello and J. C. Shillcock, Phys. Rev. C 47, R429 (1993).

5. Comment on "Energy Partition in Near-barrier Strongly Damped Collisions in $^{58}Ni + ^{208}Pb$", V. E. Viola, K. Kwiatkowski, H. Breuer and R. Planeta, Phys. Rev. C 47, 3001 (1993).

6. Origin of the Chemical Elements, V. E. Viola, Macmillan Encyclopedia of Chemistry (J. J. Lagowski, ed.), to be published.

7. Studies of IMF Emission in the $^{3}He + ^{nat}Ag$ Reaction between 0.48 and 3.6 GeV, S. J. Yennello, K. Kwiatkowski, E. C. Pollacco, C. Volant, Y. Cassagnou, R. Dayras, D. E. Fields, S. Harar, E. Hourani, R. Legrain, E. Norbeck, R. Planeta, J. L. Wile, N. R. Yoder and V. E. Viola, to be published in Phys. Rev. C.

8. Energy Dissipation and Multifragment Decay in the $^{3}He + ^{nat}Ag$ System, K. Kwiatkowski, W. A. Friedman, L. W. Woo, V. E. Viola, E. C. Pollacco, C. Volant and S. J. Yennello, submitted to Phys. Rev. C.

9. Proton Evaporation Timescales from Longitudinal and Transverse Two-proton Correlation Functions, M. A. Lisa, W. G. Gong, C. K. Gelbke, S. Pratt, N. Carlin, R. T. de Souza, Y. D. Kim, W. G. Lynch, T. Murakami, G. Poggi, M. B. Tsang, H. M. Xu, K. Kwiatkowski, V. E. Viola and S. J. Yennello, submitted to Phys. Lett.

B. Abstracts and Poster Sessions

C. Invited Talks and Seminars

1. "Multifragmentation: Deltas and Expanding Sources", V. E. Viola, Memorial Symposium for E. P. Steinberg, 204th National ACS meeting, Washington, DC, August 1992.

2. Summary Report: Second LISS Workshop on the Excitation of Nucleons and Nuclei with 1 - 15 GeV Light Ions, K. Kwiatkowski, Bloomington, IN, September 1992.

3. "Nucleosynthesis of the Light Elements", Symposium on Weak Interactions, Nuclear Astrophysical and Cosmology, V. E. Viola, National Superconducting Cyclotron Facility, East Lansing, MI, June 1993.

4. "Hot Nuclear Matter", V. E. Viola, NSF REU Program, Indiana University, July 1993.

D. Professional Activities

V. E. Viola

American Chemical Society, Division of Nuclear and Radiochemistry
    Executive committee (1993-95)
American Physical Society (fellow)
    Division of Nuclear Physics
        Fellowship Committee (1993-95)
    Division of Cosmic Ray Physics
NSF Panel on Minority Fellowships (1990-)
NSF Summer School on Nuclear Physics, Steering Committee (1988-)
American Association of University Professors
American Association for the Advancement of Science (fellow)
    Nominating Committee (1992-1994)
Sigma Xi
Phi Beta Kappa
Indiana University
    College of Arts and Sciences, Tenure Committee
    Search Committee, Dean of Faculties
    Bloomington Faculty Council, Committee on University Relations
    Department of Chemistry
        Research Ranks Committee, Chair
        Freshman Chemistry Advisory Committee
        Undergraduate Committee
    IUCF: LISS II Workshop on Excitations of Nucleons and Nuclei, Indiana University, September, 1992; Co-chairman
    Women in Science and Engineering Midwestern Meeting, Indiana University, October 1992, local steering committee

K. Kwiatkowski

National Superconducting Cyclotron Laboratory
    User's Executive Committee
IUCF, User's Executive Committee (Chair, Working Group on 4π Detector)
American Physical Society
European Physical Society
Sigma Xi
American Chemical Society, Division of Nuclear Chemistry
IEEE

V. ACKNOWLEDGEMENTS

The completion of the Indiana Silicon Sphere would not have been possible during the past year without the help of many individuals in the IU Department of Chemistry and IUCF. The Chemistry Mechanical Instrument shop (John Dorsett, Kenny Bastin, Larry Sexton, Gary Fleener, Delbert Allgood and Jeff Tate) continued to provide superb machining support for the project. The Chemistry Electronics Instrument shop (Robert Ensman, Andy Alexander, John Pohlman, Paul Ludlow, Russell Aten and Rick Sakasitz) also carried a heavy load in fabricating some 500 channels of preamp/shaper modules and detector bias supplies. Amy Van Pelt, Katherine Mann and Julia Mobley (IUCF) deserve a special vote of thanks for their efficient services in handling the large number of requisitions, deliveries and return orders placed by our group during the past year.

At IUCF, we especially appreciated the help of the wire chamber laboratory (Keith Solberg, Alan Eads and Doug Bilodeau) in bringing ISiS on-line for the first time during our May test run. Kevin Komisarcik and John Vanderwerp in the scintillator laboratory also provided needed assistance, as did the IUCF machine shop, especially Norman Jones, Phil Childress and John Cramer. Ted Capshew and Dean Duncan and his group were very helpful in supporting our computer hardware; Jack Doskow in designing the vacuum controls for ISiS; Moira Wedekind and Walt Fox in moving equipment through the shops, Ron Oram in design advice, and, as usual, Bill Lozowski for fabricating excellent targets. Chuck Foster and the experimental support group also provided much assistance in bringing ISiS on-line. Most importantly, we express our great appreciation to Dick Yoder, whose cooperation in implementing the new VME/CAMAC/XSYS data acquisition system at IUCF was extraordinary. His strong participation in both our IUCF and LNS test runs played a major role in the success of these two efforts. The operations staffs at both IUCF and LNS are thanked for their excellent beams.

We also want to acknowledge our many collaborators: Bill Friedman, University of Wisconsin; Robert Legrain, Lolly Pollacco and Claude Volant, CEN Saclay; Ralph Korteling, Simon Fraser University; Lai Wan Woo, Sabbagh Associates of Bloomington; Konrad Gelbke, Bill Lynch and Betty Tsang, Michigan State University; Herbert Breuer, University of Maryland and Grant Mathews, Livermore National

Laboratory.

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END

DATE
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2/11/94