NUCLEAR CHEMISTRY RESEARCH

Progress Report

November 1, 1975 - October 31, 1976

Nathan Sugarman and Anthony Turkevich

The University of Chicago

Chicago, Illinois 60637

NOTICE

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

NOTICE

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

October 31, 1976

MASTER

Prepared For

THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT NO. EY-76-S-02-1167

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED eb

DISCLAIMER

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

DISCLAIMER

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

ANNUAL PROGRESS REPORT ON NUCLEAR CHEMISTRY RESEARCH

CONTRACT EY-76-S-02-1167

October 31, 1976

ABSTRACT

Experiments in progress to study the dependence of cross section and gross recoil properties of various radioactive products from light (Al), medium-mass (Cu, Ag) and heavy (Bi, U) target nuclei bombarded with high-energy protons (1-400 GeV) are nearing completion. Emphasis is now being given to the details of the production processes, such as the angular and energy distributions of the products and their relation to fundamental particle interactions. Experiments are also underway on the comparison of pion and proton interactions with complex nuclei and on simple reactions involving pion production.

Three experiments using 800 MeV protons at Los Alamos on B₄C, Pb and U targets have failed to produce evidence for particle-bound polynutron systems. At this energy, less than 10^{-8} of the interactions lead to such systems.

Collaboration has continued with Los Alamos and NOAA on stable atmospheric tracers. In the last year an additional experiment was performed using both ¹²CD₄ (300 gm) and ¹³CD₄ (100 gm) at Savannah River. The distribution of the tracers found 100 km from the release point agreed qualitatively with that observed with the SF₆ (154,000 gm) that was also released.

A collaborative effort (with Dr. George W. Reed, Jr., ANL) on the study of extraterrestrial objects (meteorites and lunar samples) is continuing. Recently this work has concentrated on the distribution of halogens and mercury in lunar and meteoritic samples. The presence of isotopically anomalous mercury has been established in three more meteorites.

ANNUAL PROGRESS REPORT ON NUCLEAR CHEMISTRY RESEARCH

CONTRACT EY-76-S-02-1167

October 31, 1976

Senior Investigators: Nathan Sugarman and Anthony Turkevich.

Assisted by: Shi-Kuang Chang, John Warren,* H. Roland Heydegger,**
Karoline Wielgoz, Thanasis E. Economou, Jerome J. LaRosa, James R.
Cadieux, Robert A. Johns, Dale E. Boyce.

This document is a Technical Progress Report for the period November 1, 1975, to October 31, 1976, on nuclear chemical research performed under Contract EY-76-S-02-1167 at The University of Chicago. This report contains:

1) Reprints of three papers published during this period.

a) "Production of ^7Be , ^{22}Na , and ^{28}Mg from Mg, Al, and SiO_2 by Protons Between 82 and 800 MeV" by H. R. Heydegger, Anthony L. Turkevich, A. Van Ginneken, and P. H. Walpole, Physical Review C14, 1506 (1976).

ABSTRACT

Cross sections for the production of ^7Be , ^{22}Na , and ^{28}Mg from Mg, Al, and SiO_2 by protons in the 80 to 800 MeV energy

*Visiting Scholar, the Enrico Fermi Institute, University of Chicago, on sabbatical leave from Lakehead University, Canada.

**Chemistry Department, Purdue University, Calumet Campus, Hammond, Indiana 46323.

range have been determined by direct foil γ -ray spectrometry. These nuclides are of interest in several fields of astrophysics, cosmochemistry, and nuclear science. The values obtained are compared with other experimental values and with values predicted using empirical formulas and Monte Carlo methods. A mathematical form for the $\text{Al}(p,X)^{22}\text{Na}$ excitation function above 100 MeV is proposed.

b) "Heavy Methanes as Atmospheric Tracers" by George A. Cowan, Donald G. Ott, Anthony Turkevich, Lester Machta, Gilbert J. Ferber and Norman R. Daly, *Science* 191, 1048 (1976).

ABSTRACT

Methane-21 ($^{13}\text{CD}_4$) is potentially a useful nonradioactive tracer for testing atmospheric transport and diffusion models on a continental scale. In an experiment to demonstrate this long-range utility, the release of 84 grams of methane-21 was detected at distances of 1500 to about 2500 kilometers at concentrations of about 1 part in 2×10^{16} parts (by volume) in the air by a technique in which methane was separated and the methane-21 content was measured with a mass spectrometer.

c) " ^{196}Hg and ^{202}Hg Isotopic Ratios in Chondrites: Revisited" by S. Jovanovic and G. W. Reed, Jr., *Earth and Planetary Science Letters* 31, 95 (1976).

ABSTRACT

Additional evidence for an isotopically anomalous Hg fraction in unequilibrated meteorites has been obtained using

neutron activation to measure ^{196}Hg and ^{202}Hg followed by step-wise heating to extract the Hg. In the latest experiments Allende matrix samples released the anomalous Hg but various high-temperature inclusions did not. Nucleogenetic processes are suggested as the probable cause of the anomaly.

2) A preprint of a paper submitted for publication during this period to Physical Review C.

"Production of ^{24}Na and ^{18}F from ^{27}Al with 400-GeV protons" by S. K. Chang and Nathan Sugarman.

ABSTRACT

The recoil properties of ^{24}Na and ^{18}F from the interaction of ^{27}Al with 400 GeV protons were measured. The results showed little change in the production mode of these simple spallation reactions at 400 GeV from lower incident proton energies. No evidence was seen for inelasticity in the primary proton-nucleus interaction.

The cross section for ^{18}F production was found to be 5.9 ± 0.2 mb, 74% that of ^{24}Na .

3) Summaries of work in progress during this period. Papers based on other work completed during this and earlier periods are also in preparation.

SHORT REPORTS ON WORK PERFORMED SINCE LAST PROGRESS REPORT

1. "Search for Polyneutron Systems" by James R. Cadieux, Anthony Turkevich, Jerome J. LaRosa, Thanasis E. Economou, John Warren, and H. Roland Heydegger.

Three experiments were performed during the last contract period at the Los Alamos Meson Facility to search for particle-stable polyneutron systems. In all cases the detector reaction:

was utilized. The ${}^{212}\text{Pb}$ formed in kg quantities of lead was measured (after radiochemical isolation) via the 8.78 MeV α radioactivity of the 60.6 min ${}^{212}\text{Bi}$ daughter.

The targets (B_4C , Pb and U) were bombarded with 800 MeV protons leading to between 10^{15} and 10^{17} primary nuclear interactions. No evidence for particle-stable polyneutrons was seen. In the case of the B_4C target ${}^6_0\text{n}$ should have been produced if it were particle-stable. In the case of the Pb and U targets the experiment would have detected x_n with x up to at least 12. The limits on production probabilities set by these experiments are orders of magnitude lower than those achieved in previous searches for such systems¹ at energies below 1 GeV. However,

¹C. Détraz, Proceed. 3rd Int. Conf. on Nuclei far from Stability, Cargese, Corsica, May, 1976.

very recent work² with 24 GeV protons on tungsten, using a $\text{Zn}^{70} \rightarrow \text{Zn}^{72}$ detector suggests that such systems may be formed at higher energies.

This work is being written up for publication.

²C. Détraz, Preprint IPNO-PhN-76-28 (Nov., 1976).

2. "Studies of the Spallation of Complex Nuclei with Multi-GeV Pions" by Dale E. Boyce, Anthony Turkevich and John Warren.

Preparations are underway to study the spallation of copper by ~200 GeV pions at the Fermi National Accelerator Laboratory. The meson intensities appear adequate to establish the yields of at least eleven products in copper targets thin enough to minimize adequately the effects of secondary reactions. Several 200 GeV proton irradiations of thin copper targets have been performed to check that the intensities of interesting radioactive products will be adequate. Calculations have been made that suggest that the smaller total inelastic cross sections observed with pions than with protons may be associated with higher production of products close in mass to that of the target.

3. "Interaction of High-Energy Protons with Complex Nuclei" by S.-K. Chang, R. A. Johns, Nathan Sugarman, and K. Wielgoz.

During the past year the study of interaction of high energy protons with complex nuclei was continued. Both the cross

section measurements and recoil properties were studied for thick targets at proton energies of 1 GeV to 400 GeV on Al, Cu, Ag, and U targets. In addition, the thin target angular and range distribution of uranium fission products are being studied at 400 GeV proton energy at Fermilab in collaboration with Argonne National Laboratory and Purdue University. The following are short summaries of results achieved in the contract period.

A. Thick Target Experiments at 400 GeV.

- 1) Production of ^{24}Na and ^{18}F from ^{27}Al .

A manuscript has been submitted for publication in Phys. Rev. C. (Preprint attached to this Report.)

- 2) Study of low to medium mass products from U at 400 GeV.

The cross sections and recoil properties of $^{32,33}\text{P}$, $^{61,64,67}\text{Cu}$, and $^{105,106m,111m}\text{Ag}$ are currently under investigation at 400 GeV. These products represent a wide range of deposition energies and different reaction mechanisms. All of these products are radiochemically isolated and identified by proportional (β) counting, γ -ray and/or X-ray counting, depending on the nuclide. Irradiations were performed on the usual "forward-backward" and "perpendicular" arrangements to gain insight into the gross angular distributions of the products. In addition to the cross sections measured at 400 GeV, the cross sections of ^{105}Ag and ^{111}Ag were measured at 1 GeV.

The recoil properties for $^{32,33}\text{P}$ from U give evidence

that the emission of this "fragmentation" product is anisotropic. The range from "perpendicular" experiments, [4PW], is $\sim 12.2 \text{ mg/cm}^2 \text{ U}$, approximately 13% larger than the range in "forward-backward" experiments, [2W(F+B)], which is $\sim 10.5 \text{ mg/cm}^2 \text{ U}$. This increase in range of the perpendicular experiments is in agreement with sideward emission to the beam direction for $^{32,33}\text{P}$ from U at 400 GeV.

Preliminary analysis of the recoil properties of Cu from U at 400 GeV indicate a substantial increase for the ranges in the "perpendicular" experiments over the "forward-backward" experiments. The differences are about the same for ^{67}Cu and ^{64}Cu . The "perpendicular" range, 4PW, for ^{67}Cu is $\sim 10.3 \text{ mg/cm}^2 \text{ U}$ and the "forward-backward" range, 2W(F+B) is $\sim 8.90 \text{ mg/cm}^2 \text{ U}$. For ^{64}Cu , 4PW $\approx 8.148 \text{ mg/cm}^2 \text{ U}$ and 2W(F+B) $\approx 7.05 \text{ mg/cm}^2 \text{ U}$. These differences in 4PW and 2W(F+B) are consistent with anisotropic emission of both ^{64}Cu and ^{67}Cu from U at 400 GeV.

Cross sections and recoil properties of ^{105}Ag , $^{106\text{m}}\text{Ag}$, $^{110\text{m}}\text{Ag}$, and ^{111}Ag are currently being investigated. Results of "perpendicular" and "forward-backward" experiments show that for $^{105,106\text{m},111}\text{Ag}$, the perpendicular range, 4PW, is larger than the "forward-backward" range, 2W(F+B).

	T_p (GeV)	2W(F+B)* ($\text{mg/cm}^2 \text{ U}$)	4PW ($\text{mg/cm}^2 \text{ U}$)
^{105}Ag	400 GeV	4.06	~ 4.51
$^{106\text{m}}\text{Ag}$	400 GeV	5.46	~ 6.35
^{111}Ag	400 GeV	7.98	~ 8.26

*Chang and Sugarman, Phys. Rev. C9, 1138 (1974).

The cross sections of ^{105}Ag and ^{111}Ag at 1 GeV follow the same trend for neutron deficient and neutron excess products as found by Beg and Porile [Phys Rev 3, 1631 (1971)] for Ba and Sr isotopes. The cross section of the neutron excess ^{111}Ag falls from 62.1 mb at 0.45 GeV [Panontin and Porile, J. Inorg. Nucl. Chem. 35, 2022 (1968)] to 32.6 mb at 1 GeV. The cross section continues to decrease and has the values 24.3 mb at 11.5 GeV and 17.6 mb at 300 GeV [Chang and Sugarman, Phys. Rev. C9, 1141 (1974)]. This trend is consistent with a binary fission process where the mass of the fissioning nucleus has decreased in going from 0.45 GeV to 1 GeV and ^{111}Ag moving from the peak of the mass-yield curve. As the bombarding energy is increased the mass of the fissioning nucleus gets smaller causing ^{111}Ag to move further down the mass-yield curve for the binary fission process. The rapid rise of the cross section of ^{105}Ag from 0.22 mb at 0.45 MeV [Panontin and Sugarman, J. Inorg, Nucl. Chem. 34, 1490 (1972)] to 2.18 mb at 1 GeV shows a change in mechanism for the production of this neutron-deficient product. The cross sections at 11.5 GeV and 300 GeV are smaller with values of 2.01 mb and 1.78 mb, respectively. This trend of a rapid rise and then gradual fall in the cross section of ^{105}Ag indicates a change from binary fission to deep spallation for ^{105}Ag .

- 3) Study of near-target ($\Delta A=8-20$) spallation products and ^{149}Tb from ^{238}U bombarded with 1-400 GeV protons.

The cross sections and recoil properties of the low

deposition energy products Po, At, Rn, Fr, Ra, Ac, Pa, Th and U and the high deposition energy product ^{149}Tb are currently being examined to gain insight into the mechanisms involved for the formation of these nuclides. Since all of these products are α -emitters, α -spectroscopy combined with half-life analysis can be used to identify each species without using chemical procedures on either the target or catcher foils. The validity of this technique was confirmed by comparison of the cross sections and recoil properties of some products with those measured using chemical separations.

Early results indicated that a possible change in mechanism was occurring for the near-target nuclides since the range, $[2W(F+B)]$, had decreased by a factor of ~ 2 and F/B had increased by a factor of ~ 2 on going from 11.5 to 400 GeV. Further examination of these results led to the conclusion that these changes were due to stopping of the recoil fragments in air during the 400-GeV irradiations. Design and construction of a vacuum chamber was performed and our preliminary results indicate that $2W(F+B)$ and F/B change slightly in going from 1 GeV to 11.5 GeV and remain relatively constant to 400 GeV. Cross sections for the near-target products also exhibit little change from 11.5 GeV to 400 GeV. Some typical cross sections and recoil properties are listed below:

	T_p (GeV)	ΔA	$2W(F+B)$ (mg/cm ² U)	F/B	V ($\frac{\text{MeV}}{\text{amu}}$) ^{1/2}	σ (mb)
²²⁴ Ra	1	14	0.168	4.22	0.105	
	11.5	14	0.115	1.78	0.094	1.42
	300	14	0.115	1.97	0.093	1.50
²²⁵ Ac- ²²⁵ Ra	1	13	0.139	3.08	0.099	
	11.5	13	0.108	1.83	0.091	1.29
	300	13	0.112	1.78	0.093	1.65

The values of the cross sections and recoil results are consistent with a low deposition energy process whose mechanism does not change from 1 GeV to 400 GeV and are in good agreement with literature values obtained at lower bombarding energies.

The recoil properties and cross sections of ¹⁴⁹Tb are consistent with a deep spallation mechanism from 1 GeV to 400 GeV. The range, $[2W(F+B)]$, remains approximately constant over this energy interval, from ~ 1.95 mg/cm² U at 1 GeV to 1.83 mg/cm² U at 400 GeV, and F/B decreases from a value of 2.31 at 1 GeV to 1.51 at 300 GeV. The excitation function rises rapidly and may have the same shape as that of ¹⁴⁹Tb from gold [see Franz and Friedlander, Nuclear Physics 76, 123-128 (1966)] shifted to higher bombarding energies reflecting the extra excitation energy needed to form ¹⁴⁹Tb from U. Preliminary cross-section values of ¹⁴⁹Tb from U are:

	T_p (GeV)	σ (mb)
^{149}Tb	1	0.4
	11.5	1.90
	28	1.75
	300	1.75

B. Thin Target Experiments at 400 GeV.

A new experiment on the angular and energy distribution of ^{238}U fission and fragmentation products is underway at Fermilab in collaboration with nuclear chemists at Argonne National Laboratory and Purdue University. The recoil products from a thin UF_4 target ($\sim 300 \mu\text{g}/\text{cm}^2$) placed inside a scattering chamber were collected on Al foils ($5.8 \text{ mg}/\text{cm}^2$ thick for angular distribution and $1.8 \text{ mg}/\text{cm}^2$ thick for range distribution). These were subsequently analyzed for $^{32,33}\text{P}$ and $^{105,106\text{m},110\text{m},111}\text{Ag}$ activities by radiochemical techniques. So far two irradiations have been performed. The preliminary results show a smooth decrease of activity in the backward hemisphere. The forward hemisphere contains a peak in the 60° - 75° interval which corresponds to sideward emission of these fragments.

C. Thick Target Experiments at 1 to 11.5 GeV.

The work on the energy and target mass dependence of the recoil properties and cross section of products from Cu and Ag are being studied by gross γ -ray counting technique. The

production mode does not appear to change appreciably from 3 GeV to 11.5 GeV. It was found that the "range" increases linearly with the mass difference between the target and the product for masses down to $A \sim 35$. The kinetic energy corresponding to the "range" is in agreement with a spallation mechanism in the same mass range. For products of mass less than 35, the range is higher by 15% than the linear extrapolation from the products close to target, indicating some contribution from a fission process.

D. Revitalization of DFF Monte Carlo Computer Program for Nuclear Deexcitation (Evaporation).

The DFF Monte Carlo Code for calculation of a nuclear deexcitation process had been updated for the IBM 370 computer. Both the decay modes of the excited nucleus and the recoil property of the residual nucleus were calculated by a Weisskopf compound nuclear formulation with the help of the Monte Carlo technique. The reaction $^{27}\text{Al}(p,3p\text{n})^{24}\text{Na}$ was studied over the proton energy range of 50 to 150 MeV. The calculated recoil properties of the ^{24}Na nuclei agreed well with the experimental results up to 80 MeV. At higher incident proton energies, pre-compound emission (direct interaction) became the dominant production mechanism. The studies are being extended to include near-target spallation products from U and Ag in high-energy reactions where the residual nuclides are made with low excitation energies.

4. "Radiochemical Studies of High Energy Reactions Involving Mesons and other Exotic Particles" by Jerome LaRosa and Anthony Turkevich.

The studies of the high energy proton interaction with copper leading to products that must involve meson or other exotic particles is continuing. Four irradiations were carried out during the last year (two at Argonne National Laboratory with 11.8 GeV protons and two at Fermilab with 400 GeV protons). The yields and recoil properties of ^{65}Ni formed by $^{65}\text{Cu}(p, x^{++})$ were studied. X^{++} is one or more emitted particles with net baryon number +1.

5. "Studies on New Atmospheric Tracers" by Anthony Turkevich.*

A 1974 experiment established the possibility of detecting a 100 gm release of $^{13}\text{CD}_4$ (methane-21) after dilution in traveling ~2000 km (see attached reprint). Since then, an additional experiment has been performed on a 100 km scale at Savannah River using three atmospheric tracers: 154,000 g SF_6 ; 299 g of $^{12}\text{CD}_4$ (methane-20), and 93 g of $^{13}\text{CD}_4$. The first and last were released at the same time and place; the methane-20 was released some distance upwind. The main features of the tracer distribution at collecting stations 100 km downwind were grossly similar (see fig. 1). The two methanes, aside from the smaller amounts needed, showed factors of 5-10 better signal to background ratios at the peak than did the SF_6 . A not understood

feature is the difference by a factor of 4 of the ratio of the methanes to that of SF_6 in the air sampled as compared to the release ratio.

This work is being prepared for publication.

*In cooperation with G. A. Cowan, et al. of the Los Alamos Scientific Laboratory; G. J. Ferber, et al., of the National Oceanic and Atmospheric Administration; C. L. Kern et al. of the Savannah River Laboratory; and N. R. Daly of the Atomic Weapons Research Establishment, United Kingdom.

Figure 1. Tracer activities in air (ordinates) as a function of position of the collecting station ^(abscissa). The collecting stations were about 100 km away from the tracer release point. The abscissae are the mile posts from an arbitrary zero.

6. "Cosmochemical and Geochemical Studies" by George W. Reed, Jr.* and Stanka Jovanovic.**

The results summarized herein are based on work carried out with support from the U. S. Energy Research Development Administration and NASA. The facilities available at The Enrico Fermi Institute of The University of Chicago have been utilized in the research reported here.

A. Isotopically Anomalous Hg in Meteorites.

A major effort was made to complete the measurement of ^{196}Hg and ^{202}Hg in the Allende and Murchison meteorites. These are unequilibrated chondrites, now famous for having high temperature inclusions containing isotopically enriched ^{16}O and ^{26}Mg .

Isotopically anomalous Hg has been found in eight samples from three meteorites including the two mentioned above. This Hg was found only in the bulk or matrix material and not in the high temperature inclusions within our sensitivity. We have thus doubled the number of cases and samples that contain such Hg. This work is published in "Earth and Planetary Science Letters," 31, 95-100 (1976). A follow-up appears in "Science" 193, 188 (1976).

* Senior Chemist, Argonne National Laboratory and Senior Research Associate, The Enrico Fermi Institute, The University of Chicago.

**Employed by Argonne National Laboratory.

ABSTRACT

Additional evidence for an isotopically anomalous Hg fraction in unequilibrated meteorites has been obtained using neutron activation to measure ^{196}Hg and ^{202}Hg followed by step-wise heating to extract the Hg. In the latest experiments Allende matrix samples released the anomalous Hg but various high-temperature inclusions did not. Nucleogenetic processes are suggested as the probable cause of the anomaly.

B. Lunar Studies.

1) It has been suggested by D. D. Clayton at Rice that the moon may have accreted matter containing isotopically anomalous material. Measurements are presently under way on selected lunar samples to check this possibility. These measurements are even more time consuming than in the meteorite cases because of the very low Hg content of lunar samples.

2) The large amount of data accumulated on the abundances of halogens in lunar samples has been previously reported. These elements occur in late residual liquids. We have now reduced the data and interpreted it in terms of processes involving convection cells in the early surface magma ocean. The original sources of samples distributed over the lunar surface by basin forming impacts are identified and boundaries and dimensions of the convection cells are suggested. In press, Proc. 7th Lunar Science Conference, Pergamon Press.

ABSTRACT

A method was proposed for recognizing suites of samples which are related to the differentiation of distinct and regionally separated magmas in the early lunar surface ocean. The sample suites were identified by three Cl-P₂O₅ compositional groups. New experimental data continue to add samples to these groups. Each magma was associated with a convection cell the boundaries of which are proposed. Independent geochemical evidence supporting a limited number of early magmas is cited. Two new possible Cl-P₂O₅ groups are identified. Samples not indigenous to a given site and their possible source regions are identified. It is proposed that many Apollo 17 basalts are not locally derived.

7. "Report on Radiation Detection Equipment" by Adam Zafrans, Nathan Sugarman, S.-K. Chang, H. Roland Heydegger, Karoline Wielgoz, Thanasis E. Economou, James R. Cadieux, Jerome J. LaRosa, and Dale Boyce.

- a. Proportional Counting Systems.

A prototype of a planned new counting unit was designed and constructed by the Electronics Development Group of the Enrico Fermi Institute and is currently undergoing field testing. This all solid-state unit was designed with the primary purpose of eliminating all mechanical timers, the major source of trouble and costly maintenance, and increasing the reliability of operation.

Furthermore, the designed unit employs the highly successful Texas Instrument LED read-outs with their built-in counters and decoder-drivers on one chip, thus reducing the overall cost. Another positive feature is the addition of logic latches which virtually eliminates the possibility of missing counts during print-out time of accumulated data.

- b. Low Level Beta Proportional Counting Systems
(Wide-Beta Beckman Systems).

Extensive work was performed in renovating and improving the Low Level Beta (anti-coincidence shielded) proportional counting system. The Beckman Wide-Beta counting unit was overhauled. This included repair of the pulse signal electronics and high voltage power supplies, improvement of the

electrical grounding of the detectors and shielding, replacement of the detector windows and modification of the scaler/printer unit. The backgrounds of the two detectors in this system have now been reduced to about 0.2 counts per minute and stability over long counting periods of time (i.e. 10,000 min) has dramatically improved.

The quiet power supply for the counting room for this equipment was also repaired. Electrical wiring was enclosed in an all-metal conduit and connected to a special silent ground to prevent R-F pick-up and normal line noise problems. A mechanical voltage regulator was revamped and two new capacitive line filters were installed on the line to eliminate fast-transient electrical disturbances.

Another Beckman Wide-Beta system borrowed from the Argonne National Laboratory is being overhauled and prepared for use. Extensive electronics changes are being made and shielding for low background counting needs to be constructed. This unit operates on P-10 gas (Ar-CH₄ mixture).

c. Ge-Li Gamma Spectroscopy Systems.

All of our detectors were equipped with the field proven solid state liquid nitrogen Level Detectors which monitor the nitrogen consumption and will enable us to act promptly in case of slow leaks as well as catastrophic failures.

Most detectors performed well during the past year with little or no degradation of resolution.

d. Intrinsic Germanium Low Energy Spectroscopy Systems.

One of the two Intrinsic Germanium low energy photon detectors failed last January and was replaced by Ortec under warranty with a detector having comparable characteristics. An interior graded lead shield 20 cm thick was constructed in the low level counting lab to house the new detector. This effort resulted in substantial decrease in the background in the energy region of interest.

A master/slave clock time base module was acquired from Nuclear Data to allow the memory of our ND-2400 multichannel analyzer to be split in half and operate two detectors simultaneously.

Both systems are equipped with Level Detectors for monitoring the liquid nitrogen consumption.

e. Multichannel Analyzers and Peripheral Equipment.

During the year we put some effort in improving the performance of our Nuclear Data multichannel analyzers by replacing a number of suspected intermittent switches in the ADC's. The result was quite surprisingly successful and we shall continue with other modules.

We also introduced some mechanical improvements into our fast Franklin printer and replaced some worn parts in the Kennedy tape deck.

f. Alpha Counting Systems.

A fourth silicon Alpha Detector using a modified Ortec pre-amplifier was added to our detection equipment for use

in the Polyneutron Search Experiment. The detector was acquired from our own LASR group and meets or exceeds commercial quality. Additional preamplifiers, scalers, and an autofinger for IBM typewriter print-out were also purchased.

8. "Report on Target Transport System for Fermilab Bombardments"
by E. Blume, A. Zafrans, S.-K. Chang, Robert A. Johns,
James R. Cadieux, Dale Boyce, Jerome J. LaRosa, and Nathan
Sugarman.

Nuclear chemistry bombardments of simple targets are performed in the Meson Area of Fermilab on a parasitic basis. The target must be introduced to intercept the beam by remote control while the Accelerator is in operation and cannot affect experiments operating on prime time downstream from this area. The system used for transporting the target earlier was a "toy" electric engine running on track mounted alongside a tunnel area. Because of the haste with which the old system was assembled and because of mistreatment of the track by technicians working on magnets and other equipment, the system deteriorated to the point that less than half of the attempts to achieve a bombardment were successful. Moreover, the target area was downstream of a chamber containing considerable material which caused a halo of "secondaries" to accompany the primary proton beam.

Anticipating an extended shut-down of the Accelerator in the late Spring, we decided to revamp the whole transport system.

New track was purchased and mounted securely on a rigid support. Two new engines were purchased and extensively modified to be more reliable for climbing the steep incline by "gearing-down" the wheel drive and adding weight and better rubber tires to the wheels to increase the friction on the track. Also a heavy duty Lambda power supply with remote sensing and remote vernier capabilities was constructed by the Electronics Development Group of The Enrico Fermi Institute. With this supply it is possible to control the speed and direction of the train from a master control panel. The new transport system was installed in the late Spring. Because it may be necessary to remove this system hurriedly for equipment service in this area, the system is readily dismountable. The target area is now upstream of the chamber which generated secondaries and the quality of the beam has been markedly improved. The performance record of the new system is about 90%.

Experiments on the recoil properties of near-target nuclides demonstrated that bombardment in air led to spurious results. A vacuum chamber about 3 in. in diameter and 2.5 in. deep was constructed to contain targets for these bombardments. The beam enters the chamber through a 0.75 in. window made of 1-mil aluminum. The target is mounted in the chamber; the chamber is evacuated for about 2 days to less than 0.01 Torr., the target is bombarded, and the pressure is measured after the bombardment, normally less than 0.6 Torr. This chamber is mounted

on a flat-bed of a train car and is pushed into place by the modified engine. More than ten bombardments have been performed in vacuum, all successful.

9. "Report on Special Equipment for LAMPF Irradiations (Polyneutron Search)" by E. Blume, Anthony Turkevich, James R. Cadieux and Jerome J. LaRosa.

The three high intensity irradiations at LAMPF required the construction of special targets and radioactive target handling devices. The targets (up to 100 g/cm^2 uranium) were exposed to about 5 amperes of 800 MeV protons, with consequent heat dissipation of about 5 Kwatts. The produced radioactivity was many hundreds of curies. Special water cooled target holders were constructed, as well as remotely activated devices to handle the radioactive items on the time scale of the experiment (less than 10 hrs.).

The chemical operations were performed on large scale (~ 20L) equipment constructed at Chicago and implemented in the hot-cell facilities at LAMPF. The cooperation of all members of the LAMPF operation staff was essential and is hereby acknowledged.

Effort of Principal Investigators Devoted to Project

Principal Investigator Nathan Sugarman estimates that he devoted about 70% of his time to this project from February 1, 1976 to October 31, 1976 (including 100% for the months of July and September). He estimates that he will devote about 60% of his time from November 1, 1976 to January 31, 1977.

Principal Investigator Anthony Turkevich estimates that he devoted about 30% of his time to this project for the period February 1, 1976, to June 15, 1976, and 60% of his time from June 15, 1975 to November 31, 1975 (the summer under Los Alamos auspices). He estimates that he will devote 40% of his time from December 1, 1976 to January 31, 1977.