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December 31, 1972

NATHAN SUGARMAN

AND

ANTHONY TURKEVICH

DISCLAIMER

TECHNICAL PROGRESS REPORT ON NUCLEAR CHEMISTRY RESEARCH

CONTRACT AT(11-1)-1167

December 31, 1972

Senior Investigators: Nathan Sugarman and Anthony Turkevich

Assisted by: H. R. Heydegger, S.-K. Chang, Karoline Wielgoz, Patricia M. Starzyk, Maynard Cheney, Edwin Doak, Jerome LaRosa, and Kenneth Inn.

This document is a Technical Progress Report for the period December 31, 1971, to December 31, 1972, on nuclear chemical research performed under Contract AT(11-1)-1167 at The University of Chicago. This report contains: 1) reprints of two papers published during this period, "Mass Yield Distribution and Charge Dispersion in 450 MeV Proton Fission of ^{238}U" by J. A. Panontin and N. Sugarman, J. Inorg. Nucl. Chem. 34, 1485-1502 (1972) (COO-1167-10) and "Thin-Target Cross Sections for Some Cr, Mn, Fe, Co, Ni, and Zn Nuclides Produced in Copper by 82- to 416-MeV Protons" by H. R. Heydegger, C. K. Garrett, and A. Van Ginneken, Phys. Rev. 6C, 1235-1240 (1972) (COO-1167-12), 2) preprints of four papers published during this period (reprints not yet available), "Production of ^{149}Tb from Gold by 0.2 to 0.5 GeV Protons" by H. R. Heydegger and A. Van Ginneken, Nucl. Physics A 196, 156-160 (1972) (COO-1167-20), "Half-Lives of ^{171}Ta and ^{172}Ta" by S. K. Chang and M. C. Cheney, Phys. Rev. 6C, 1898 (1972) (COO-1167-21), "^{204}Pb in Apollo 14 Samples and Inferences Regarding Primordial Pb Lunar Geochemistry" by R. O. Allen, Jr., S. Jovanovic and G. W. Reed, Jr., Proceedings of the Third Lunar Science Conference, Geochim. et Cosmochim. Acta, Suppl. 3, Vol. 2, 1645 (1972) (COO-1167-23) and "Trace element relations between Apollo 14 and 15 and other lunar samples, and the implications of a moon-wide Cℓ-KREEP coherence and Pt-metal non-coherence" by G. W. Reed, Jr., S. Jovanovic and L. Fuchs, Proceedings of the Third Lunar Science Conference, Geochim. et Cosmochim. Acta, Suppl. 3, Vol. 2, 1989 (1972) (COO-1167-24) and 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. "Mass Yield Distribution and Charge Dispersion in 450 MeV Proton Fission of ^{238}U" by J. A. Panontin and N. Sugarman (J. Inorg. Nucl. Chem. 34, 1485 [1972]) (COO-1167-10).

ABSTRACT

The independent and/or cumulative cross-sections of 26 isotopes of silver, cadmium, indium, tin, and antimony from the fission of ^{238}U with 450 MeV protons have been measured. The isotopic yield distribution for these elements is presented along with the charge dispersion for six mass chains, 109, 115, 117, 125, 127 and 129. The values of the most probable charge, Z_p, for 14 mass chains were calculated and the variation of A/Z_p with A in the mass region 100-130 was determined. For A values between 100 and 120, the value of A/Z_p is relatively constant at a value of 2.424 ± 0.004 if the charge dispersion width is assumed to be constant at a value of 2.90 ± 0.10 Z units. In the mass region, 125-129, a width of 3.21 Z units and a slightly higher value of A/Z_p, 2.430 ± 0.004, are required to account for the data. A mass yield curve encompassing this region of A was also determined.

2. "Thin-Target Cross Sections for Some Cr, Mn, Fe, Co, Ni, and Zn Nuclides Produced in Copper by 82- to 416-MeV Protons" by H. R. Heydegger, C. K. Garrett and A. Van Ginneken (Phys. Rev. 6C, 1235 [1972]) (COO-1167-12).

ABSTRACT

Thin-target cross sections were determined by radiochemical means for the production of the radionuclides ^{65}Zn, ^{63}Ni, ^{56}Ni, ^{60}Co, ^{58}Co, ^{57}Co, ^{56}Co, ^{59}Fe, ^{55}Fe, ^{54}Mn, ^{52}Mn, and ^{51}Cr by 82-, 111-, 187-, 283-, and 416-MeV protons incident on natural copper. The experimental results are compared with values in the literature, expected trends in the excitation functions, and values calculated via empirical formulas and Monte Carlo treatments.

3. <u>"The Production of ^{149}Tb from Gold by 0.2 to 0.5 GeV Protons"</u> by H. R. Heydegger and A. Van Ginneken (Nucl. Physics, <u>A 196</u>, 156 [1972]) (COO-1167-20).

ABSTRACT

The production of ^{149}Tb from gold by 200-450 MeV protons has been observed with cross sections (alpha branch only) as follows: 0.0028 ± 0.0011 μb at 218 ± 14 MeV, 0.23 ± 0.09 μb at 384 ± 21 MeV, and 0.84 ± 0.34 μb at 434 ± 24 MeV.

4. <u>"Half-Lives of ^{171}Ta and ^{172}Ta"</u> by S. K. Chang and M. C. Cheney (Phys. Rev. <u>6C</u>, 1898 [1972]) (COO-1167-21).

ABSTRACT

The half-lives of ^{171}Ta and ^{172}Ta were determined. The nuclides were produced by the spallation reaction $^{181}Ta(p,pxn)$ at a proton bombarding energy of 450 MeV. The half-life of ^{171}Ta was found to be 23.3 ± 0.3 min, in good agreement with the literature

value. A previously unreported γ ray at 1087 keV is probably assignable to ^{171}Ta decay. The half-life of ^{172}Ta was found to be 36.7 ± 0.4 min.

5. "^{204}Pb in Apollo 14 Samples and Inferences Regarding Primordial Pb Lunar Geochemistry" by R. O. Allen, Jr.*, S. Jovanovic† and G. W. Reed, Jr.** (Proceedings of the Third Lunar Science Conference, Geochim. et Cosmochim. Acta, Suppl. 3, Vol. 2, 1645 [1972]) (COO-1167-23).

ABSTRACT

^{204}Pb has been measured in Apollo 14 samples and its aqueous (pH 5-6) leachability determined. Soils contain 5-9 ppb of ^{204}Pb with 7-35% leachable; a fragmental rock contains 1.5 ppb ^{204}Pb with ~ 30% leachable. ^{208}Pb and Bi were also measured in some samples; both were more leachable on the average than ^{204}Pb. Primordial lead is present in two forms, as a volatile, soluble salt on surfaces and as a constituent of a metal or metal related phase.

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*Permanent address: Chemistry Department, University of Virginia, Charlottesville, Virginia.

†Employed by the Argonne National Laboratory.

**Dr. George W. Reed, Jr. is employed as a member of the scientific staff of the Argonne National Laboratory. He is also a Research Associate of The Enrico Fermi Institute of The University of Chicago.

6. "Trace element relations between Apollo 14 and 15 and other lunar samples, and the implications of a moon-wide Cℓ-KREEP coherence and Pt-metal non-coherence" by G. W. Reed, Jr.*, S. Jovanovic† and L. Fuchs† (Proceedings of the Third Lunar Science Conference, Geochim. et Cosmochim. Acta, Suppl. 3, Vol. 2, 1989 [1972]) (COO-1167-24).

ABSTRACT

The halogen, Hg, Ru, Os, U, Li and Te contents in Apollo 14 soils 14259 and 14163, fragmental rocks 14321 and 14305, crystalline rock 14310 and some Apollo 15 soils are given. Br concentrations as high as a ppm are observed for the first time. The Cℓ remaining after aqueous leaching of samples is correlated with the total P_2O_5 in soils from all sites. Ru and Os are not coherent with the other Pt-metals nor with each other; a lunar fractionation process appears to be necessary.

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*Dr. George W. Reed, Jr. is employed as a member of the scientific staff of the Argonne National Laboratory. He is also a Research Associate of The Enrico Fermi Institute of The University of Chicago.

†Employed by the Argonne National Laboratory.

7. "Production of Rare-Earth Nuclides from Uranium by 11.5-GeV Proton Bombardment" by P. M. Starzyk and Nathan Sugarman.

A manuscript is under preparation for publication in Physical Review C based on the thesis of P. M. Starzyk for the Ph.D. degree in the Department of Chemistry at The University of Chicago. A preliminary draft of the manuscript will be submitted in the near future. The Abstract of this preliminary draft is given below.

ABSTRACT

The thick-target thick-catcher recoil properties of 23 rare-earth nuclides, produced in the interaction of 11.5-GeV protons with uranium, were measured in the mass range 135 to 165. The ratio of the range of a product from multi-GeV protons to that from 450-MeV protons, called the "relative range", was calculated for all nuclides studied in the mass region 82-165. The dependence of the relative range on the charge displacement of the product from stability was similar for all nuclides studied. For neutron-excess products, the relative range was around 0.95 and dropped sharply over two Z-units to 0.48 for very neutron-deficient products. This relative range curve was used to analyze isobaric charge dispersion curves into three individual charge dispersion curves corresponding to two fission mechanisms (a

low-excitation energy process, Fission I, and a high-excitation energy process, Fission II) and a non-fission (Spallation) mechanism.

The charge dispersion curve attributable to the non-fission process has a width (FWHM) of about 2 Z-units and a peak between 1.8 and 3.6 Z-units on the neutron-deficient side of stability. The fractional isobaric cross section for this process decreases with decreasing mass number from 0.98 at mass 170 to about 0.10 at mass 100 and then increases with decreasing mass number to 0.49 at mass 74. The products are neutron-deficient of low range and with forward-to-backward recoil ratios much closer to unity than expected. The range values increase almost linearly with ΔA from 2.2 mg/cm^2 U at ΔA of 70 to 5.6 mg/cm^2 U at ΔA of 160. The velocity imparted to the target nucleus in the beam direction as a result of the cascade, $v_{\parallel}$, was calculated from the forward-to-backward ratio and a range-energy relation. The value of $v_{\parallel}$ decreases from 0.04 (MeV/amu)$^{\frac{1}{2}}$ at ΔA of 70 to 0.01 (MeV/amu)$^{\frac{1}{2}}$ at ΔA of 100 and then increases to 0.02 (MeV/amu)$^{\frac{1}{2}}$ at ΔA of 160.

The charge dispersion curve attributable to the Fission II process has a FWHM of about 1.5 Z-units and its peak position is approximately constant at 1.2 Z-units from stability on the neutron-deficient side. The fractional isobaric cross section is roughly constant at 0.06 for mass numbers between 100 and 150.

The relative range for these products is 0.9 and the F/B values are also closer to unity than expected for a high-excitation energy process.

8. "Modified Two-Step Model of Nuclear Fission at High Proton Energies" by S. K. Chang and N. Sugarman.

The mechanism of the production of copper isotopes from uranium at high proton energies is not well established. The kinetic energy distribution observed for the copper nuclides is reasonably narrow, similar to that of the neutron-rich fission products. However, the mean momenta are smaller than predicted by the liquid-drop model and the observed F/B values are closer to unity than expected. It is possible that these nuclides are the products of the fission of lower mass nuclei which are the residues of a high deposition-energy process that involves the emission of large fragments both in the cascade and the evaporation stages.

Assuming that the cascade fragments are emitted only in the forward hemisphere in the laboratory frame, we were able to fit the angular distribution of the low mass fragments in the backward hemisphere by the function, $W(\theta) = a + b \cos^2 \theta$, where θ is the angle of emission in the moving frame, and an η value of the moving frame derived from the kinetic energy measurements at 15°, 90°, and 165°. The cascade contribution is then the difference between the observed angular distribution and that calculated as just described (assumed to be associated with an evaporation process).

Two analyses have been made. The angular and energy distribution curves of ^{24}Na from bismuth at 3 GeV reported by Cumming et al. (Phys. Rev. 134, B167 [1964]) were analyzed. It was found that the fast cascade process contributes about 10% to the ^{24}Na yield, the remainder by evaporation. Assuming that the copper nuclides are produced after the emission of a ^{24}Na fragment, either in the cascade or evaporation process, this analysis leads to an expected F/B $\sim$ 1.8 for copper isotopes while that observed at 12 GeV is $\sim$ 1.1.

The same analysis was performed with the ^{11}B spectra from uranium at 5.5 GeV reported by Poskanzer, Butler and Hyde (Phys. Rev. 3C, 882 [1971]). We estimate that about 14% of the ^{11}B fragments are emitted during the fast cascade process and 86% by evaporation. The calculated F/B value for copper nuclides is $\sim$ 1.5, again higher than the observed value at 12 GeV of $\sim$ 1.1.

If the assumptions of this analysis are correct, cascade fragments of higher mass or of higher yield must be associated with the production of copper isotopes from uranium by bombardment with 12 GeV protons.

9. "The Production of ^{149}Tb from Au and other Heavy Elements at Low Proton Energies" by H. R. Heydegger*, A. Van Ginneken† and A. Turkevich.

The extension of the production cross section of ^{149}Tb by protons from Au to energies below 450 MeV (see preprint and abstract) has revived interest in the cross section for such reactions at energies of about 100 MeV. The value obtained previously at 100 MeV (in the picobarn range) has a large uncertainty. Such a nuclear reaction at these energies has special interest because the mechanism is probably different from that at higher energies, and involves a drastic change in the neutron to proton ratio from that of the target.

It is planned to study the production of ^{149}Tb from gold and nearby targets at around 100 MeV, probably making use of the high intensity proton beams available at LAMPF or Brookhaven.

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

†Radiation Physics Section, National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510.

10. "Fission and Spallation of Bismuth Induced by 12-GeV Protons" by S. K. Chang and N. Sugarman.

The purpose of this experiment is the understanding of the mechanism of the production of neutron-deficient nuclides in the fission-product mass region by high-energy projectiles.

The recoil properties of product nuclides in three mass regions from ^{209}Bi bombarded by 12-GeV protons at the Argonne Z. G. S. accelerator have been measured by the thick-target thick-catcher technique. Tantalum and tungsten nuclides are considered to be the residues of a spallation process, silver, palladium and molybdenum nuclides are in the fission-product mass region, and copper isotopes lie between the fission-product and the so-called "fragment" regions. For the tantalum and tungsten nuclides, the F/B value is $\sim$ 2.0 and the "effective range" $\sim$ 0.5 mg/cm^2 of Bi. For the neutron-rich fission products, the F/B value is $\sim$ 1.15 and the range $\sim$ 7.5 mg/cm^2 Bi. For the neutron-deficient nuclides, the F/B value is $\sim$ 1.30 and "effective range" $\sim$ 3.5 mg/cm^2 Bi. For the three copper isotopes studied, the F/B values are all $\sim$ 1.2, while the range decreases from 7.9 mg/cm^2 Bi for ^{67}Cu to 5.6 mg/cm^2 Bi for ^{61}Cu.

11. "Interaction of 12-GeV Protons with Uranium" by S. K. Chang and N. Sugarman.

Work in continuing on the recoil properties of products formed by the bombardment of uranium with 12-GeV protons at the Z. G. S. accelerator of the Argonne National Laboratory. The "effective ranges" and F/B ratios of gold, mercury, tungsten, tantalum, silver, palladium, molybdenum, and copper nuclides from uranium are being studied by the thick-target thick-catcher technique. In order to understand the nature of the reaction mechanisms at 12 GeV responsible for production of the various products, an experiment is in progress to compare the angular and differential range distributions of these products.

During the Z. G. S. shut-down in the summer, one of the authors, S. K. Chang, spent three weeks at the Brookhaven National Laboratory performing experiments at the A. G. S. accelerator operating at 12 GeV.

12. "Interaction of 200-GeV Protons with Uranium" by S. K. Chang and N. Sugarman.

The Nuclear Chemistry Users Group at the National Accelerator Laboratory submitted, and received approval for, a proposal for the irradiation of various targets with high-energy protons in external beams at the new Accelerator. The initial period of work, as agreed upon by the Nuclear Chemists, involves the comparisons of results of reactions studied at proton energies up to 30 GeV with those at 200 GeV, or above. The commitment of the University of Chicago group involves the recoil studies of various products produced from heavy target bombardment. Several irradiations have been performed to date on various targets with 200-GeV protons at low intensity. One of the irradiations was performed on a uranium target assembly prepared by us. The bombardment was of ~ 18 hr duration and the proton intensity ~ 1.6×10^{10} protons sec^{-1}. A portion of the target assembly, consisting of a thick uranium target with thick Al catchers was analyzed in our laboratory.

The recoil properties and relative cross sections of ^{67}Cu, ^{105}Ag, ^{106m}Ag, ^{111}Ag and ^{172}Ta were measured. The preliminary results indicate that the recoil properties of ^{67}Cu and ^{172}Ta are about the same at 200 GeV as at 12 GeV, whereas the ranges of the silver isotopes are surprisingly somewhat higher at 200 GeV than at 12 GeV. Some of the cross sections are also somewhat higher at 200 GeV than at 12 GeV. Inasmuch as only one experiment has been performed, and nothing is known about the effect of secondary particles produced in the interaction of 200-GeV protons on the results, it is somewhat premature to arrive at conclusions at this time. More work will be done on these reactions during the coming year.

13. "Recoil Properties of Light Mass Nuclides from the Bombardment of Uranium by High-Energy Protons" by M. C. Cheney and N. Sugarman.

The recoil properties of copper, nickel and cobalt nuclides produced in the interaction of high energy protons with uranium are being studied. These nuclides are of particular interest because they are in the mass region between fission products and the so-called "fragment" products. Standard radiochemical procedures have been modified to provide the additional decontamination required in working with reactions at very high energies. Both solvent extraction and ion-exchange techniques are used. The samples were counted on both Ge(Li) γ-ray detectors and β-ray proportional counters.

The recoil properties of ^{28}Mg from uranium were also studied. The F/B value is high, consistent with preferential forward production, a characteristic of fragment production.

Since the shut-down of the University of Chicago Synchrocyclotron, most of the work was done at the Z. G. S. of the Argonne National Laboratory at a proton energy of 11.5 GeV. During the temporary shut-down of the Z. G. S. in the summer, one of the authors, M. C. Cheney, worked at the Brookhaven National Laboratory with the targets bombarded at the A. G. S. accelerator.

14. "Production of ^{26}Al from Geochemically Important Targets by 90-450 MeV" by H. R. Heydegger*, A. Turkevich, E. Doak† and J. LaRosa.

^{26}Al ($t_{\frac{1}{2}} = 7.4 \times 10^5$ yr) is a radionuclide of special importance in establishing the chronology of events in meteorites and lunar samples. The quantitative interpretation of the abundances of this nuclide found in such samples requires a knowledge of the excitation functions for its production from the more abundant target materials found in rocks, i.e. Mg, Al, Si, Ca, T, and Fe. Such data in the energy range of importance (< 500 MeV) are rather sparce. The (p,n) reaction on ^{26}Mg leading to long lived ^{26}Al is also of theoretical interest due to the large isotopic spin change involved in the process.

The work on the production cross sections of this nuclide from Mg, Al, Si and Fe at several proton energies between 90 and 450 MeV is continuing. The targets had been irradiated at the University of Chicago Synchrocyclotron for periods between 20 and 140 hrs before the machine was shut down. After allowing the short-lived radioactivities to die away, the long-lived ^{26}Al in them has been isolated and is being purified. It will be measured in the low level counting laboratory. The amounts found will be related to the production of ^{24}Na (whose production cross sections are known) in the same targets, thus giving the cross sections for making ^{26}Al by protons in these targets.

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

†Chemistry Department, State University of Michigan, East Lansing, Michigan 48823.

15. "Cross Sections for the Production of ^{7}Be and ^{22}Na in Mg, Al, Si, and Fe Targets by 80-450-MeV Protons"

by H. R. Heydegger*, C. K. Garrett†, A. Van Ginneken**, P. H. Walpole‡, and A. Turkevich.

A standard monitor for nuclear reactions in the 100-500 MeV range is ^{24}Na, the production cross section for which has been studied extensively. The short half-life of this nuclide (15 hr) makes it inappropriate for monitoring the very long irradiations needed to produce species such as ^{26}Al (see Section 12).

Cyclotron irradiations of Mg, Al, Si, and Fe targets at various energies have been performed and the radioactivity of the targets has been measured without chemical separation. These results have yielded values for the production cross sections of ^{22}Na and of ^{7}Be relative to those for ^{24}Na. A manuscript describing these results is under preparation.

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

†Center for Naval Analyses of the University of Rochester, 1401 Wilson Boulevard, Arlington, Virginia 22209.

**Radiation Physics Section, National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510.

‡Laboratory for Astrophysics and Space Research, University of Chicago, Chicago, Illinois 60637.

16. "Preparation for a Polyneutron Search at the Los Alamos Meson Facility" by A. Turkevich*, H. R. Heydegger† and T. Economou.

Although bound nuclear systems involving only 2, 3, 4 or 5 neutrons (and no protons) appear to be excluded both theoretically and experimentally, the situation is not quite so clear for the case of the six neutron system. A proposal is being prepared to search for a bound ^{6}n system produced at the high intensity 800 MeV beam at LAMPF. An activation method of detection will be used.

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*This work was started during visits to Los Alamos.

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

17. "Radiochemical Analysis of Freshly Fallen Meteorites"* by H. R. Heydegger† and A. Turkevich.

Work in this area has been largely confined to the continuing measurements of long-lived radioactive species (particularly those isolated from the Pueblito de Allende meteorite), and in writing-up completed experimental work.

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†Chemistry Department, Purdue Univ., Calumet Campus, Hammond, Ind. 46323.

18. "Comparative Study of the Distribution of Trace Elements In Meteoritic Matter" by S. Jovanovic* and G. W. Reed, Jr.†

The following is the Abstract of a talk presented at the 35th Annual Meeting of the Meteoritical Society, University of Chicago, November, 1972.

"In an attempt to further understand the condensation and accretion of meteoritic matter, we have undertaken experiments designed to identify the sites of some trace elements. As examples of highly volatile, moderately volatile and refractory elements, Tl, Ag and Ba were selected. Selective leaching and dissolving of phases after the procedures of Vilcsek and Wanke and Shima and Honda were carried out.

"In the initial experiments only equilibrated and unequilibrated ordinary chondrites (UOC) were studied in order to restrict the number of variables. In these the chemical composition of the major and minor elements is essentially the same for a given class of chondrite but some trace element contents vary greatly.

"The data from the pairs of samples when presented as histograms of the fraction of the element in each solution, suggest that the elements studied are similarly situated in the equilibrated and the unequilibrated ordinary chondrites. However, the pair of bronzites do not exhibit the same profile for Tl as the two pairs of hypersthenes. The trace elements appear to be associated with more than one phase in a given class of meteorites, regardless of whether the meteorites are equilibrated or not. Further pairs of meteorites are being run but it is clear that the picture of incorporation of volatile trace elements in meteoritic material may be much more complex than suggested by their condensation temperatures or simply by their relative enrichment in the UOC."

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*Employed by the Argonne National Laboratory.

†Dr. George W. Reed, Jr. is employed as a member of the scientific staff of the Argonne National Laboratory. He is also a Research Associate of The Enrico Fermi Institute of The University of Chicago.

19. "Report on Radiation Detection Equipment" by Adam Zafrans, Nathan Sugarman, H. R. Heydegger, Karoline Wielgoz, S.-K. Chang, and Maynard C. Cheney.

a. Proportional Counting Systems

A prototype of a superior and highly reliable proportional counting system was thoroughly tested and extensively used during the past year. The unit, developed and built by the Electronics Shop of the Enrico Fermi Institute employs the latest in integrated circuitry and completely eliminates mechanical time counters. Instead, electronic preset and total time counters are used and all the visual readouts are of the LED (Light Emmitting Diode) type. Circuitry has also been incorporated which can at any time link this system to a minicomputer and yet allows for a separate data printer.

Complementing this system is a new pre-amplifier consisting of two integrated circuits, a differential amplifier followed by a monostable. Both chips are mounted next to each other near the detector tube and are highly immune to noise. This arrangement eliminates the need for the more commonly used adjustable discriminator.

Most of the proportional counting units performed well during this period but required more frequent changes of mechanical time counters and printers.

b. Ge-Li Gamma Spectroscopy Systems

One of our original Ge-Li detectors used for gamma-ray measurements has been factory rebuilt and upgraded allowing us to take advantage of the new techniques for resolution improvement. Another innovation is a separate bias filter network mounted outside the pre-amplifier. A new dewar was acquired for this detector after the old one developed excessive leakage.

A Ge-Li detector in the Low-Level Laboratory suffered a serious decrease in the resistance of the crystal, resulting in a ten-fold reduction in resolution and a 40% decrease in efficiency. Present needs make it necessary to continue to use this system. At the appropriate time, the detector will be returned to the manufacturer for reprocessing.

c. <u>Alpha-Fission Counting System</u>

A new two parameter multichannel analyzer system with digital spectrum stabilization has been acquired for use in studies of nuclides decaying by alpha emission or spontaneous fission. The addition of a new Nuclear Data pulse height analyzer to be used for alpha particle analysis required the construction in the Electronics Shop of the Enrico Fermi Institute of two switching units which will enable the sharing of peripheral equipment, an oscilloscope and a typewriter. In order to improve the long range counting stability of this system, a special module, which will convert the existing single pulser into a double pulser and will also provide two extra blocking pulses for the PHA memory, was designed and is being prepared for operation.

This module will enable us to take full advantage of the digital stabilizer of the system.

d. Single Channel NaI(Tl) X-Ray Counting System

A new counting system for X-rays was assembled. It consists of a 2 mm thick NaI(Tl) crystal with a photo-multiplier tube, a single-channel analyzer and a scaler-timer. The system is especially useful for X-ray counting of samples of low activity.

Effort of Principal Investigators Devoted to Project

Principal Investigator Nathan Sugarman estimates that he has devoted about 65% of his time to this project from April 1, 1972 to December 31, 1972 (including 85% for the months of July and September). He estimates that he will devote about 50% of his time from January 1, 1973 to April 1, 1973.

Principal Investigator Anthony Turkevich estimates that he has devoted about 10% of his time to this project for the period April 1, 1972 to June 15, 1972, and 20% of his time from September 1, 1972, to December 31, 1972. He estimates that he will devote 20% of his time from January 1, 1973, to April 1, 1973. The period June 15, 1972, to September 1, 1972, was spent at Los Alamos working on programs related in interest to those of this project.