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TECHNICAL PROGRESS REPORT ON NUCLEAR CHEMISTRY RESEARCH

CONTRACT AT(11-1)-1167

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Senior Investigators: Nathan Sugarman and Anthony Turkevich

Assisted by: H. R. Heydegger, S.-K. Chang, Karoline Wielgoz, Patricia M. Starzyk, Maynard Cheney, and E. Doak.

This document is a Technical Progress Report for the period December 15, 1970 to December 31, 1971 on nuclear chemical research performed under Contract AT(11-1)-1167 at The University of Chicago. This report contains summaries of work in progress during the contract year, and reprints of two papers published during this period, "Activation Analysis Determination of Uranium and ^{204}Pb in Apollo 11 Lunar Fines" by Anthony Turkevich, G. W. Reed, Jr., H. R. Heydegger and J. Collister, Proceedings of the Second Lunar Science Conference, Vol. 2, pp. 1565-1570, The M.I.T. Press (1971) and "The Halogens and Other Trace Elements in Apollo 12 Samples and the Implications of Halides, Platinum Metals, and Mercury on Surfaces" by G. W. Reed and S. Jovanovic, Proceedings of the Second Lunar Science Conference, Vol. 2, pp. 1261-1276, The M.I.T. Press (1971). Papers based on work completed during this and earlier periods are also in preparation.

SHORT REPORTS ON WORK PERFORMED SINCE LAST PROGRESS REPORT

1. "Mass Yield and Charge Distribution in 450-MeV Proton Fission of U^{238}" by John A. Panontin and Nathan Sugarman.

This work has been completed and a manuscript has been accepted for publication by The Journal of Inorganic and Nuclear Chemistry. [A preliminary draft of the manuscript was appended to the Technical Progress Report of December 15, 1970.]

2. "Thin Target Cross Sections for Some Cr, Mn, Fe, Co, Ni, and Zn Nuclides Produced in Cu by 82- to 416-MeV Protons" by H. R. Heydegger, C. K. Garrett, and A. Van Ginneken.

This work has been completed and a manuscript has been submitted to The Physical Review for publication. [A preliminary draft of the manuscript was appended to the Technical Progress Report of December 15, 1970. This was modified to include the results of Vegas-Monte Carlo calculations performed at Brookhaven National Laboratory by Dr. Gerhart Friedlander and his associates.]

3. "Isomer Yield Ratios and Average Spin of Primaries in 450-MeV Proton Fission of U^{238}" by John A. Panontin and Nathan Sugarman.

This work has been completed and a manuscript will be sent to the Journal of Inorganic and Nuclear Chemistry for publication. [A preliminary draft of the manuscript was appended to the Technical Progress Report of December 15, 1970.]

4. "The Production of ^{149}Tb from Au by 100-450-MeV Protons"

by H. R. Heydegger, A. Van Ginneken*, and Anthony Turkevich.

The production of ^{149}Tb from gold has been widely used as a beam intensity monitor for protons in the GeV range. It has also been used as a detector of high energy hadrons in shielding applications. This reaction is almost uniquely suitable for these purposes because of its high energy effective threshold (greater than 600 MeV), the ease in measuring the resulting alpha radioactivity, and the availability of extremely pure foils. Previous measurements have been confined to proton energies above 600 MeV. There is, however, both practical and theoretical interest in the cross section for this reaction at lower energies.

Gold foils were irradiated for periods of 15 min to 1 hour with the internal proton beam of The University of Chicago Synchrocyclotron at energies of approximately 120, 220, 380 and 430 MeV. Rare earth radioactivities were isolated from these targets and measurements were made of the alpha particle emission therefrom. The production of ^{149}Tb has been observed down to 220 MeV. Data analysis and interpretation are in progress.

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*Radiation Physics Section, National Accelerator Laboratory.

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

A study of the recoil properties of rare-earth nuclides produced by the 11.5-GeV proton bombardment of uranium has been completed and is being written up as a thesis by P. M. Starzyk for the Ph.D. degree in the Department of Chemistry at The University of Chicago.

The chemical separation used in this study was a simple precipitation of all of the rare-earth elements as a group. The activities of the samples isolated in this manner were then measured on a high-resolution solid-state Ge-Li detector. The validity of this technique was demonstrated by the agreement of the recoil properties determined by this technique for rare-earth nuclides from 440-MeV proton bombardments with those determined previously by use of ion-exchange separation for the rare-earth nuclides.

The general results of the range measurements on the rare-earth nuclides demonstrate the same behavior at 11.5 GeV as that reported previously at high energy for other nuclides. The range of a neutron-excess rare-earth nuclide from 11.5-GeV proton bombardment is approximately the same as its range from 440-MeV proton bombardment. However, the range of a neutron-deficient rare-earth nuclide from 11.5-GeV proton bombardment is about one-half of its range from 440-MeV proton bombardment. In order to correlate the results of the rare-earth range study with range data for different elements, a parameter was needed which eliminated the difference in range due to the difference in mass number.

Division of the 11.5-GeV range of a nuclide by the 440-MeV range of the same nuclide eliminated this difference. This ratio, called the "relative range", was calculated for many nuclides in the mass region 82-165. Since the range of a series of nuclides from 11.5-GeV bombardment changes dramatically as the nuclides become more neutron-deficient, the relative range of a nuclide is clearly related to its distance from stability. This distance from stability is expressed in terms of the parameter $Z_A - \langle Z_{eff} \rangle$, where Z_A is the charge corresponding to maximum stability for mass number A and $\langle Z_{eff} \rangle$ is the average effective charge of the product. The effective charge of a nuclide of mass number A is determined by fitting all isobars of mass number A to a single mass parabola instead of the two mass parabolas with different Z_A values needed in those cases where nuclear shell crossing occurs. For a cumulatively-produced nuclide, the average effective charge $\langle Z_{eff} \rangle$ is calculated by summing the effective charges of the nuclide and its precursors, each nuclide weighted by its relative yield.

It was found that the same general curve described the behavior of the relative range with $Z_A - \langle Z_{eff} \rangle$ for all mass numbers considered. Two almost constant values were found for the relative range - 0.95 for neutron-excessive nuclides (fission products) and 0.48 for neutron-deficient nuclides ("deep" spallation products). The sharp drop between these two values occurs on the neutron-deficient side about 1-2 Z units from stability for the heavier nuclides. Lighter-mass nuclides ($74 \leq A \leq 82$) show the decrease in relative range much closer to stability.

The relative range curves determined above were used to decompose charge dispersion curves into individual charge dispersion curves for fission and "deep" spallation mechanisms. The result of this decomposition of the charge dispersion curve is that the part of the charge dispersion curve which was attributed to fission is still double-humped and corresponds to two distinct fission mechanisms - a low-energy process, essentially the same as that at 440 MeV, and a high-energy process. However, the charge dispersion curve for mass number 74 was decomposable into charge dispersion curves for only two mechanisms - "deep" spallation and low-energy fission.

6. "High-energy Nuclear Reactions of ^{209}Bi Induced by 440-MeV and 12-GeV Protons" by S.-K. Chang and Nathan Sugarman.

The recoil properties of product nuclides from ^{209}Bi in three mass regions are being measured by the thick-target thick-catcher technique. The purpose of the experiment is the understanding of the mechanism of the production of neutron-deficient nuclides in the fission-product mass region by high-energy projectiles. 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 lies on the boundary between the fission and fragment regions.

The "effective ranges" of the tantalum and tungsten nuclides measured (^{173}Ta, ^{174}Ta, ^{175}Ta, ^{176}Ta, ^{177}Ta, ^{179}Ta, ^{178}W) at 12 GeV are about the same as those at 440 MeV. The F/B values, however, are about a factor of 2 smaller. For 440-MeV protons, in the mass region of the fission products, the neutron-deficient nuclides (^{100}Pd, ^{101}Pd, ^{103}Pd, ^{105}Ag, $^{106\underline{m}}$Ag) have almost the same range and F/B values as those of the neutron-rich nuclides (^{99}Mo, ^{109}Pd, ^{110}Ag, ^{111}Ag, ^{112}Ag). For 12-GeV protons, however, the neutron-deficient nuclides studied have only half the range of the neutron-rich nuclides. The F/B values of the neutron-deficient nuclides are only 20% larger than those of the neutron-rich nuclides, much smaller than expected from a spallation process. The mechanism for the formation of the neutron-deficient products is thought to involve the preferential forward emission of fragments. The recoil properties of copper isotopes (^{61}Cu, ^{64}Cu, ^{67}Cu) were also studied. Compared with the values at 440 MeV, the F/B value of ^{67}Cu at 12 GeV increased by 10% whereas the "effective range" decreased by 30%. This result may also be attributed to a fragmentation process at high energies.

In order to understand better the nature of the reaction mechanism at high energy, an experiment has been begun to compare the angular and differential range distributions of various reaction products. It is hoped that a comparison of the recoil properties of the neutron-deficient palladium isotopes with those of tantalum, considered to be formed by a spallation process, and with those of ^{99}Mo, a fission product, will lead to an understanding of the formation mechanism of the neutron-deficient products. The irradiations are being performed in the internal beam of the ZGS at The Argonne National Laboratory.

7. "Recoil Properties of Spallation Products from the Bombardment of Uranium by High-Energy Protons" by Maynard C. Cheney and Nathan Sugarman.

The recoil properties of several nuclides produced by the interaction of high-energy protons on uranium are being investigated. Initial studies in the region of tantalum and rhenium products have been extended to include lighter elements such as copper and silver. Standard radiochemical procedures have been modified where necessary to provide the additional decontamination required in working with reactions at very high energies. Since the shutdown of the Enrico Fermi Institute Synchrocyclotron, all work has been done at the ZGS of the Argonne National Laboratory at 11.8 GeV. Some future work has also been scheduled at the AGS of the Brookhaven National Laboratory at approximately the same bombarding energy.

Data from gamma spectroscopy and proportional counting of samples from thick-catcher experiments have been subjected to computer analysis for determination of recoil properties. Capability for gamma spectroscopy of both forward and backward catchers simultaneously has been obtained at low cost by operating two Ge-Li crystals into a single 4096-channel memory. Values for F/B, FW, and BW for the nuclides studied have been found to be in reasonable agreement with extrapolated values from lower energy reactions. It is intended that this study will be extended to more elements, particularly those of lighter mass, in order to try to understand the relation between the yields and recoil properties of very heavy and very light fission products. It is expected that this information will contribute to the understanding of the anomalous range results observed for certain light elements (e.g. isotopes of copper) and neutron-deficient nuclides in the fission-product mass region.

8. "The Production of ^{26}Al in Mg, Al, Si, and Fe Targets by 90-450-MeV Protons" by H. R. Heydegger, Anthony Turkevich and E. Doak.

^{26}Al is a radionuclide whose abundance has been determined in a large number of meteoritic and, more recently, lunar surface samples. These specific radioactivity values are taken as a measure of the duration of the exposure of such unshielded materials to cosmic radiation. A more quantitative interpretation of such values requires a knowledge of the excitation functions for the production of ^{26}Al from the more abundant target materials found in siliceous materials, e.g. Mg, Al, Si, and, to a lesser extent, Ca, Ti, and Fe. Such cross-section data are, unfortunately, not available in the literature, due, presumably, to the long irradiation times required to produce measurable quantities of this long-lived ($\approx 10^6$ y) radionuclide. The (p,n) reaction on ^{26}Mg is also of theoretical interest due to the very large isotopic spin change required in the nuclear reaction.

In order to obtain values for the production cross section for ^{26}Al from the most important of these targets at several proton energies, three Mg targets, three Al targets, two SiO_2 targets, and one Fe target were irradiated with the internal beam of The University of Chicago Synchrocyclotron for periods ranging from about 20 to about 140 hours. Unfortunately, the shutdown of The University of Chicago Synchrocyclotron prevented complete coverage of the energy range available for each of the targets. In order to be able to use the full internal beam of the cyclotron, the standard target holders were modified to provide more efficient heat transfer to the probe head and the probe head was modified to permit continuous cooling by running cold water. These modifications permitted employment of full beam intensity even with Mg (melting point 651° C) as the target.

After allowing the targets to cool, the ^{26}Al in them will be isolated using standard radiochemical procedures, and the cross sections determined relative to those of ^{24}Na and ^{22}Na produced in the same target (see Section 9).

9. "Cross Sections for the Production of ^{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 Anthony Turkevich.

The standard radiochemical monitor for nuclear reactions in the 100-500 MeV range is ^{24}Na, whose production cross section from various targets, especially aluminum, has been studied extensively. The short half-life of this nuclide (15 hr) makes it inconvenient for monitoring the very long irradiations needed to produce nuclear species such as ^{26}Al (see Section 8).

Cyclotron irradiations of Mg, Al, Si and Fe targets at various energies have been performed and the radioactivity of the targets is being measured without chemical separation. These results will yield values of the cross sections of ^{22}Na and, hopefully, ^{7}Be relative to those of ^{24}Na.

10. "Radiochemical Analysis of Freshly Fallen Meteorites"*

by H. R. Heydegger and Anthony 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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11. "^{204}Pb in Apollo 14 Samples" by R. O. Allen, Jr.*, S. Jovanovic†, and G. W. Reed, Jr.‡.

(The following is the Abstract of a talk presented at the Third Lunar Science Conference, Houston, Texas, January 9, 1972.)

"The primordial isotope of Pb, ^{204}Pb, has been measured in several Apollo 14 samples by fast neutron activation analysis. This method avoids the uncertainties caused by large blank corrections necessary in other procedures. The lability of

^{204}Pb was also studied by its leachability in aqueous solution. Such a measurement is of interest because lead is one of the more readily volatilized elements; it is associated with volcanic emmanations as $PbCl_2$. The existence of an apparently parentless, more labile, Pb component in lunar soil and breccia has been noted by other investigators. A primordial labile lead possibly associated with this component was sought in this work.

"In previous measurements of Pb by the activation technique, reactor irradiations were utilized; in this work, fast neutrons produced by (d,n) reactions in the ANL 60-inch cyclotron were used as well. The $^{206}Pb(n,\alpha)^{203}Hg$ reaction makes the measurement of ^{206}Pb feasible. Short reactor irradiations permit ^{208}Pb measurements.

"^{204}Pb was measured in samples and in sieved fractions of soils 14163,152 and 14259,119; in the "clod" 14049,35 and in the fragmental rock 14321,185. A 620 mg piece of 14321,185, free of cut surfaces, was crushed and 470 mg run as a "representative" sample. After irradiation all samples were leached for 10-15 minutes with a hot aqueous solution at pH 5-6. In a few cases Bi and ^{208}Pb were measured. ^{204}Pb concentrations (Table 1) range from 5-8 ppb in the soils, including sample 14049,35. Even under the mild leaching conditions employed 10-30% of the ^{204}Pb was soluble. This amount of mobile Pb is comparable to that resulting from strong acid leaching and low temperature (600-700°C) volatilization as reported by other investigators. The sieved fractions from the soils yield nearly the same ^{204}Pb concentrations as the bulk samples. However, the 14163,152 fine fraction contained more Pb in both residue and leach, whereas the 14259,119 coarse fraction contained more. Thus no grain size correlation can be made. This indicates that a single vapor deposition process probably cannot account for the labile ^{204}Pb. The finer and coarser fractions appear to have had different histories, acquiring different amounts of nonleachable and leachable Pb, but ending up with nearly the same total amount of Pb.

"The clod 14049,35, containing 6 ppb ^{204}Pb of which 1.3 ppb is leachable, is indistinguishable from the soils. The rock 14321,185 has lower ^{204}Pb, 1.55 ppb, than any other reported. Interestingly, about the same amount of leachable ^{204}Pb is present as in the other samples. Since this rock has not been reconstituted since formation (as soil may have been) and since vapor deposition (above) does not necessarily explain the labile Pb, it seems that this Pb was acquired at the time, or before, the fragments were consolidated into rock 14321,185.

"The residual and leachable Bi contents in the 14259,185, 14049,35 and 14259,119 are given in the Table. The trends in ^{204}Pb are duplicated in the Bi. Even more Bi is leachable, 4.75 vs. 1.11 ppb, in the 14049,35 sample. The residual and leachable ^{208}Pb contents in 14163,152 and 14259,112 are 2 and

<1 ppm and 1.3 and 0.5 ppm, respectively. The aqueous leachability of Bi as well as that of primordial and radiogenic Pb suggests that volatile transport is an important process in the distribution of some elements on the moon."

Table 1. Lead and Bismuth in Apollo 14 Samples.

	^{204}Pb (ppb)		Bi (ppb)	
Sample**	Residue	Leach	Residue	Leach
14163,152	5.6±1.7	2.5±2.5		
14163,152>150μm	2.3±0.14	0.005±0.008		
<150μm	10 ±1	2.8±0.5		
Σ	8.2	2.1		
14259,119	4.4±0.5	0.5±0.2		
14259,119	5.1±0.6	0.4±0.2	1.7	<0.4
14259(119,112)				
>150μm	7.0±1.4	4.1±1.0		
<150μm	5.8±0.7	1.1±0.2		
Σ	6.0	1.6		
14049,35	4.7±0.8	1.3±0.2	1.1	4.8
14321,185	1.1±0.2	0.45±0.23	0.9	0.6

**Sample weights were 0.3 - 1.0 gm.

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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.

12. "Concentrations and Lability of the Halogens, Platinum Metals and Mercury in Apollo 14 and 15 Samples" by G. W. Reed, Jr.*, S. Jovanovic† and L. H. Fuchs†.

The following is the Abstract of a talk presented at the Third Lunar Science Conference, Houston, Texas, January 9, 1972.

"Four sets of elements were measured, the halogens, the electropositive elements, Li, Ba and U, the platinum metals, Ru and Os and the element Hg. Neutron activation is the technique used. Besides studying the concentration, distribution and hot water leachability of these elements our attention has turned to the volatilization of some of them in the heating experiments in which Hg is extracted.

"Because of the complexity of the fragmental rocks some preliminary mineralogical characterization was necessary as a guide for sampling. The mineralogy of the dark fractions of 14305,64 and 14321,185 is generally similar to that of the light fractions, but there are marked contrasts between the texture of the dark and that of the light. The dark of both samples consists of relatively large sub-angular fragments of plagioclase, pyroxene and olivine, up to 0.1 mm in diameter, embedded in a fine-grained (0.01 mm) matrix of silicates and abundant needles or plates of smaller (1-3 μ) opaque grains. The hard and porous dark clasts appear to be partially recrystallized breccias. The light fraction, interstitial to the well-defined dark clasts, contains an assortment of less consolidated angular mineral and glass grains and both

recrystallized and unaltered rock fragments. Thus, at least two thermal events were involved. Rock 14310 contains orthopyroxene; this is the first occurrence of the mineral in any of the lunar crystalline rocks we have examined and may in some respects be related to its unique chemistry.

"Cl contents cluster around 45 ppm. F contents are similar to those previously measured: of the order 100-300 ppm in Apollo 14 soils and <100 in igneous rock 14310,124 fragmental rocks and in Apollo 15 soils. I concentrations span the range (2→200 ppb) previously reported. Br concentrations as high as a ppm were observed in a number of samples, including soil, fragmental and igneous rocks. Previous results placed Br in Apollo 12 soil and breccia and Apollo 11 soil, breccia and igneous rocks at a few tenths ppm and that in Apollo 12 igneous rocks at a few tens ppb. The Cl/Br ratios for most of the Apollo 14 samples cluster near 50 as was the case for Apollo 11. The ratios of insoluble/soluble Cl and Br at all four sites show a distribution similar to terrestrial basalts. Another result of interest is the larger concentrations of Cl and Br in the dark relative to the light separates from 14305 and 14321.

"Ru and Os are expected to be depleted in lunar surface material as are most siderophile elements. The Ru concentrations, Table 1, are similar to those reported for Apollo 12 rocks. No significant enrichment is apparent in the soils. On the other hand the amounts of Os decrease from soil to fragmental to igneous rock in the order ~67→24→11 ppb. The Os concentration in rock 14310 is similar to that in Apollo 11 and 12 soils. This rock has been a closed system possibly since the Imbrium event. Its enhanced (x10) Os content relative to Apollo 11 and 12 basalts suggests that it may be remelted breccia. The still larger Os contents in Apollo 14 fragmental rock and soil require further additions of an exogenous component. The fragmental rocks which contain basaltic clasts could have acquired the additional Os between the time of formation of the basalts and consolidation. The soils either continued to acquire Os or originated from a more Os rich strata or region.

"Hg concentrations in general are less than 2-3 ppb with the notable exception of the trench samples which contain 7-9 ppb Hg. The trench samples also contain the higher concentrations of labile Hg (volatilized at <130°C). These trench samples do not show a variation with depth probably because of mixing during sample collection. The 15231 soil sample from under a boulder should have been cold and has a large fraction of labile Hg compared to that in 15091, a nearby soil sample exposed to lunar daytime temperatures.

"The most striking aspect of the Apollo 14 Hg measurements is the large release above 450°C during stepwise heating. In samples from other sites only a small fraction of the Hg remained above this temperature; in Apollo 14 most samples still retained 30% or more Hg. We interpret the presence of

Hg in highly retentive sites as being due to high temperature equilibration. Since these samples are known to be associated with the impact that excavated the Imbrium basin both high temperature quenching and shock implantation may account for the Hg in retentive sites.

"The cold traps in which Hg was collected during the stepwise heating were observed to contain other radioactivities, notably Br. Losses due to volatilization had not been considered serious before since Br results obtained on both heated and unheated samples agreed quite well. Most of these samples, however, were Apollo 12 igneous rocks. Experiments are now conducted so as to account for all possible losses. It has been established that not only Br but other elements, F, Ru, and Os for instance, may be volatilized. In Apollo 14 soils and fragmental rock 14305 up to 10% of the Br was volatilized below 450°C and most of the remainder between 450° and 1200°C. In igneous rock 14310 20 to 60% of the Br volatilized. It would be interesting to measure 14053 which is more like mare basalts in which little loss appears to have occurred. Ru and Os volatilization was low, few % or less. 15231 and 15091 are exceptions; up to 75% of the Os and 29% of the Ru were mobilized. F results may also be affected when F was determined on samples from which Hg had been extracted.

"Apollo 15 soils from the front and the mare region have significantly lower Cl and Os, but not Br, I and Ru, than the Apollo 14 soils. Such differences between coherent elements probably requires a lunar fractionation process.

"We have not completely assessed our data in the light of meteoritic contributions. The examination of the samples did reveal several possibilities. Metal particles in the dark parts of 14321,185 and 14305,64 have Ni and Co contents within the range of meteoritic metal. The metal of 14321,185 contains inclusions of schreibersite and a carbide (4.3%C hence too low for cohenite). The light part of 14305,64 contains polycrystalline aggregates of olivine and three chondrule-like objects from 0.8-1.5 mm in diameter. Two of these "chondrules" were sectioned; they resemble meteoritic chondrules in shape only.

"Our trace element results make resolution of an external contribution difficult. For instance the Ru/Os in 14310 and the Apollo 15 soils fall near the meteoritic ratio of 1.7 whereas the Apollo 14 soil and fragmental rocks have much lower ratios and Apollo 12 soil and rocks have higher ratios. Data for other elements may elucidate this problem; for instance, we observed a linear correlation between the Ni and Os contents of 14259, 14305 and 14310, and also between 12033, 12070 and 10084.

Table 1. Halogens, ruthenium, osmium, mercury and other trace elements in Apollo 14 and 15 Samples

Sample	Cl r† (ppm)	Cl l† (ppm)	Br r (ppm)	Br l (ppm)	I†† (ppb)	Ru (ppb)	Os (ppb)	Hg ≤130°C (ppb)	Hg total (ppb)	U r (ppm)	U l (ppm)	Li r (ppm)	Li l (ppm)	Te (ppb)
14163,108	42	9.4	1.1	0.23	9.2					1.8	0.02	19	<0.07	0.34
14163,108			0.29			17	45	0.12	2.7	4.1		19	<0.1	
14259,96	37	18	0.17	0.03	4.0					4.0	<0.02			nd
14259,96>150μm	32	3.7	0.70	0.21	23					4.6	0.03	20	<3.5	nd
14259,96 <74μm	36	7.9	0.26	0.30	172					6.0	0.19	12	≤0.11	nd
14259,96			0.19			19	50	0.17	1.8	3.3				
14259,96>150μm			0.21			26	70			4.0				
14259,96 74-150μm			0.19			14	46			2.7				
14259,96<74μm			0.43			37	14			8.9				
sum of fractions			0.26			22	77			4.7				
14148,13 trench top						(17)	107	1.1	7.2					
14156,3 " middle						(8.8)	40	1.4	8.6					
14149,21 " bottom						(38)	82	2.1	8.2					
14321,185* (light)	46	3.8	0.33	0.10	82					2.0	0.01	32	<1.3	≤54
14321,185 (dark)	61	3.9	0.91	0.11	51					6.3	0.01	40	<0.4	≤19
14305,84-1**						≤23	31	0.83	2.4					
14305,84-2						< 8.3	20	0.28	1.5					
14305,64 (light)						≤33	22	0.80	11					
14305,64 (dark)						≤14	22	0.11	0.68					
14305,64 (light)	9.3	2.0	0.11	0.08	30					5.8	0.03	50	<1	≤62
14305,64 (dark)	20	1.3	0.38	0.59	41					3.7	0.03	56	<1	≤65
14310,124-1**						~15	10	0.35	0.76					
14310,124-2						<13	11	0.22	0.94					
14310,124	4.2	1.7	0.75	0.10	4.7					3.5	0.01	27	0.14	~51
14310,122-C						11	12	18	41					
15091,32	11	7.3	0.42	0.29	2.1					0.96	0.01	16	<0.2	~ 9
15091,32						25	24	0.5	10					
15251,28	21	3.4	0.52	0.25	8.3					2.0	0.02	16	-	nd
15041,32	20	-	0.29	0.28	2.8					1.7	0.02	15	~0.2	nd
15041,32						15	28	1.3	3.0					
15231,29						16	14	8.1	11					

* 14321,185 and 14305,64 are interior samples ** 14310,124 and 14305,84 are exterior samples. 1=outer 2 mm, 2=just below surface

† r = residue after leaching, l = leach solution †† I detected in leach only

( )lower limits due to possible volatilization losses

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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.

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13. "Report on Radiation Detection Equipment" by Adam Zafrans, Nathan Sugarman, Karoline Wielgoz, S.-K. Chang, Patricia M. Starzyk, Maynard C. Cheney, George W. Reed, Jr., and H. R. Heydegger.

a. Ge-Li Gamma Spectroscopy Systems

During the earlier part of the year our Ge-Li gamma detector was factory redrifted and at the same time it was equipped with a new low-noise FET pre-amplifier. This created a new up-to-date detector with much improved resolution, particularly in the low energy region.

The installation of a second Ge-Li detector for Gamma Spectroscopy enabled us to take full advantage of the already existing electronics and thus forming two fully compatible but independent radiation detection systems.

Throughout the greater part of the year we have been using the "dual-singles" mode of operation in which our 4096-channel analyzer effectively performed as two single-parameter 2048-channel analyzers.

Our tape recorder and Interface required some attention during this period but for most part full advantage has been taken of the computer compatible tape recordings.

b. Low Energy Photon Spectroscopy System

A new LEPS system was installed, thoroughly tested, and extensively used throughout the year. This system, with its Ge-Li X-ray detector and multi-channel analyzer performed very well and proved a most useful tool for spectral analysis of nuclides in the X-ray region where high resolution was the prime objective.

c. NaI System for X-ray Counting

A new super low-noise photo-multiplier tube with a 2mm thick NaI crystal was acquired and a special voltage divider base was constructed. This detector is very useful for X-ray counting where good efficiency rather than resolution is of prime concern.

d. Proportional Counting Systems

Our radiation detection laboratories (counting rooms) with 12 methane-flow proportional counters used for alpha and beta particle detection have been in almost constant use this past year. Some of the detector tubes have been rebuilt and some new ones were constructed. The electronics of these units required periodic attention, particularly the mechanical timers. We had also encountered transformer failure in some of the Fluke High Voltage supplies.

A new type of methane-flow cylindrical proportional counter tube with a horizontal anode wire has been constructed and is in the process of undergoing extensive testing.

A new IC (integrated circuit) type pre-amplifier and discriminator are being developed.

e. Low-Level Laboratory

Most of the equipment in the Low-Level Laboratory has been in continuous use during the past year. Measurements of the ^{26}Al radioactivity isolated from the preliminary experiment (see Section 8) have been made by γ/γ coincidence in a shield in the 50-foot deep well. A second beta-detection system for use in the Low-Level Laboratory is still under construction. The Ge-Li detector has been utilized for the measurements of all of the targets and monitors resulting from the cross section surveys described above in Sections 8 and 9.

f. Sharp-Beckman Low Beta Counting System

The Electronics Shop designed and built a new printing unit for the Low-Beta Beckman System. The unit, which utilizes integrated circuitry, consists of two "blind" scalers operating essentially in parallel with the scalers from the Beckman unit. No counts are lost in the operation of the printer whereas counts are usually lost in printing-out information or in the resetting of the printer. Each printer is controlled by a common preset timer in order to obtain permanent data independent of the data being accumulated in the Beckman scalers.

Effort of Principal Investigators Devoted to Project

Principal Investigator Nathan Sugarman estimates that he has devoted about 70% of his time to this project from April 1, 1971 to December 31, 1971 (including 100% for the months of July and September). He estimates that he will devote about 60% of his time from January 1, 1972 to April 1, 1972.

Principal Investigator Anthony Turkevich estimates that he has devoted about 15% of his time to this project for the period April 1, 1971 to July 1, 1971, 100% of his time during July, 1971, and 30% of his time from September 1, 1971 to December 31, 1971. He estimates that he will devote 10% of his time from January 1, 1972 to April 1, 1972.