Title

A SEARCH FOR SUPERHEAVY ELEMENTS WITH HALF-LIVES BETWEEN A FEW MINUTES AND SEVERAL HUNDRED DAYS, PRODUCED IN THE 48Ca+248Cm REACTION

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DISCLAIMER

A SEARCH FOR SUPERHEAVY ELEMENTS WITH HALF-LIVES BETWEEN A FEW MINUTES AND SEVERAL HUNDRED DAYS, PRODUCED IN THE ^{48}Ca + ^{248}Cm REACTION*

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ABSTRACT

The results of recent unsuccessful attempts to synthesize and identify superheavy elements at the Lawrence Berkeley Laboratory SuperHILAC are described. A thin ^{248}Cm target was irradiated with ^{48}Ca ions at an average energy in the target of 255 MeV. Direct counting of thin recoil foils for short-lived spontaneous fission activity was done. Two long irradiations were also made and radiochemical group separations for the superheavy elements were carried out.

In the first radiochemical experiment, a thin superheavy element sample was prepared and has been continuously counted for spontaneous fission events in a dual surface barrier coincidence counter. In the second experiment, two superheavy element fractions were obtained and were counted for spontaneous fission events; the two fractions contained those elements that co-precipitated with copper sulfide from either an acid or basic solution.

INTRODUCTION

A description and some of the results are reported from experiments using the first ^{48}Ca ion beams accelerated at the SuperHILAC of the Lawrence Berkeley Laboratory. These experiments were performed in July and August of 1976. The primary emphasis in this work was placed on the synthesis and identification of superheavy elements (SHE) that are thought to make up the "island of stability" centered at $^{298}114$ [1]. The SHE's in this region have been predicted to exist with a range of half-lives, some long enough to study in the laboratory with radiochemical techniques [2]. The compound nucleus reaction $^{48}Ca + {}^{248}Cm \rightarrow [{}^{296}116]^*$ has been suggested to be among the most favorable reactions for producing superheavy elements [3]. The advantages of this target-projectile combination are: First, the relative neutron richness of both the ^{248}Cm and ^{48}Ca make it possible to produce a compound nucleus close to the central region of the island of stability. Secondly, ^{48}Ca is a doubly magic nucleus, therefore its large mass defect contributes to a minimization of the excitation energy of the compound nucleus. Thirdly, ^{48}Ca is a relatively low Z projectile when compared with Kr and Xe, so that a large fraction of the total reaction cross section is expected to result in fusion and formation of a compound nucleus as in the case of the reaction of ^{40}Ar with ^{238}U [4,5].

The calculated Q value and excitation energy of the compound system are given in Table 1. It has been suggested that the formation of the compound nucleus would require more energy in the entrance channel

than that necessary to overcome the Coulomb barrier between two tangent spheres [7,8]. For this reason the average bombarding energy of the ^{48}Ca was chosen to be approximately 20 MeV above the Coulomb barrier.

Even though the nuclear decay modes and half-lives predicted for the SHE's have large uncertainties [2], it is generally agreed that the decay chain of any SHE isotope produced will end with a spontaneous fission (SF) event. For this reason the identification of any SHE's found in these experiments was based upon the detection of the predicted spontaneous fission activity.

The predicted chemical properties indicate that SHE's with atomic numbers 108 to 116 will be homologs of the elements from osmium to polonium [9]. According to these predictions we were able to make the following assumptions about the chemical properties of the SHE's. (1) The SHE's 108-116 will form insoluble sulfides in acid solution. (2) The SHE's will form stable anionic bromide complexes [10]. (3) The SHE's with atomic numbers 110 and 112 should be noble metals, and thus may be easily reduced from aqueous solution [11-14]. (4) The metals of atomic numbers 112 and 114 may be as volatile or more volatile than Hg because of the closures of the $6d^{10}$ (element 112) and $7P_{1/2}^{2}$ (element 114) electronic shells [15].

Since many actinide elements, including the ^{248}Cm target, undergo spontaneous-fission decay it was necessary to isolate any SF events associated with compound nucleus formation from all other sources of spontaneous-fission activity. In these experiments this was accomplished by using recoil techniques and chemical separation

techniques. The principle sources of interference resulted from the production of actinide elements such as ^{256}Fm, formed either directly by deep inelastic or quasi-elastic transfer reactions, or through decay of ^{256}Md and ^{256}Es parents, elastic scattering of ^{248}Cm, and thermal transfer of the ^{248}Cm target material to the catcher foils.

EXPERIMENTAL

The two ^{248}Cm targets used in these experiments were supplied by E. K. Hulet of the Lawrence Livermore Laboratory. These targets consisted of 570 and 500 μg of ^{248}Cm (97% isotopically pure) deposited as CmF_3 by vacuum sublimation onto a 2.21 mg/cm^2 Be support. The CmF_3 was deposited over an area 6 mm in diameter yielding target surface densities of 2.0 and 1.7 mg/cm^2 ^{248}Cm. Figure 1 shows a schematic representation of the target system that was used in the experiment. The relative positions of the target, projectile energy monitoring system and secondary Faraday cup that were used in the first experiment are shown in Fig. 1a. Here in order to measure the beam energy the target had to be withdrawn from the path of the beam. In subsequent work the scattering foil (∿10 μg/cm^2 Au on ∿23 μg/cm^2 Al) was moved ahead of the target as shown in Fig. 1b.

In all the experiments the reaction products recoiled out of the target and were collected on either Be or Al foils. These collectors consisted of a stack of 8 or more 200 μg/cm^2 Al foils on brass support rings or a single 2.2 mg/cm^2 Be foil held against a water cooled Al backing plate. The catcher foils were placed at three different

geometries as indicated in Fig. 2. This allowed various degrees of angular discrimination against noncompound nucleus reactions. The entire target assembly was located at the exit of the SupeHILAC in the zero degree beam line, thus permitting a minimization of beam losses from bending, etc. The peak beam level of the ^{48}Ca ions was approximately one microampere (electrical) on target, at an average charge state of +14. This is equivalent to 4.5×10^{11} particles per second. The beam energy for all experiments was 303 MeV at the exit of the SuperHILAC. After passing through the Be support, the energy ranged from 243 to 267 MeV in the ^{248}Cm target. Thus the average energy in the target was 255 MeV. Repeated measurements showed that the more reliable Faraday cup at the rear of the assembly (Figs. 1a, b) consistently gave beam intensity readings that were a factor of 1.6 higher than the readings obtained by the target and recoil catcher assembly. Integrated beam intensities obtained from the target-recoil catcher assembly were subsequently corrected using this factor. A summary of the experiments with their bombarding conditions is given in Table 2.

A. Radiochemical Separation Experiments

Two chemical separations were performed. The first and more elaborate chemical procedure (Scheme I) was based on a procedure developed for the separation of superheavy elements from thick uranium targets following heavy ion irradiations [16]. A flow scheme of this procedure is given in Fig. 3. In this experiment a 25 $\mu g/cm^2$ Al cover foil was placed between the target and the 2.2 mg/cm^2 Be recoil

catcher. The Be was in position B of Fig. 2. The cover foil broke during the bombardment, perhaps due to insufficient cooling. As a result 5000 SF counts per minute of ^{248}Cm, from thermal transfer from the target, were found on the surface of the Be catcher foil when it was checked before chemical processing. Because of the ^{248}Cm contamination on the Be, both of the volatile metal bromide fractions contained traces of ^{248}Cm which nullified any results from these fractions. However, the nonvolatile SHE fraction was separated from the ^{248}Cm activity with a separation factor of approximately 10^{12} using cation exchange adsorption of the actinides. The SHE's are expected to form complexes with bromide ions in 0.6 M and 0.1 M HBr/Br_2 solutions. By forming anionic complexes such as $[MBr_4]^{-2}$, the SHE's should be eluted through the cation-exchange column. The actinides do not form such complexes and are held by the column. The final solution was reduced to dryness and accumulated organic residue from the columns was destroyed by perchloric acid. The remaining salts which would have contained any nonvolatile SHE's were taken up in a dilute $HBr/Br_2/HNO_3$ solution and placed on a thin Vyns film [17]. Vyns is a vinyl acetate-vinyl chloride copolymer that we have found to be very resistant to decomposition by acid solutions and was therefore superior to otherwise mechanically stronger films [18]. A small amount of colloidal Teflon spreading agent was also used to prepare the carrier free sample with an approximate diameter of 6mm. The chemical yield of ^{195}Au, ^{207}Bi and ^{192}Ir tracers, added at the dissolution of the Be, were found to be 20%, 35% and 50% respectively.

The sample was placed between two surface barrier detectors for continuous SF counting. The sample was checked after 109 days and was found to have retained its mechanical integrity. The Total Kinetic Energy (TKE) spectra from a ^{252}Cf source deposited in an identical manner on a thin Vyns film and measured in this system is shown in Fig. 4.

A second radiochemical search following a bombardment of somewhat shorter duration was carried out using a stack of eighteen 200 $\mu g/cm^2$ aluminum recoil foils held at position A of Fig. 2. A schematic diagram of this separation procedure (Scheme II) is shown in Fig. 5. Following this 12 hour bombardment the foils were removed and monitored for any SF activity. Only the first foils showed a significant amount of SF activity, perhaps from thermal transfer of ^{248}Cm from the target. Foils 3 through 12 inclusive were combined by placing them into a common dissolving vessel. These foils were expected to contain the compound nucleus recoil products. A carbonized beam spot was found on both the front and back face of each of the recoil foils, probably from some residual butyl acetate that had been the solvent for colloidal Ag which was used to glue the foils to the supporting brass rings. The foils were dissolved in a few milliliters of 6 M HCl and 50 λ of HNO_3. H_2O_2 was added to promote the dissolution of the carbon. The vapors and therefore any volatile elements were trapped in a 2 M HCl solution. The carbon from the Al dissolution was filtered by a 6 mm diameter cellulose nitrate filter and counted with a surface barrier detector under 2π geometry for alpha and SF events.

The 2 M HCl solution in the condensing trap was added to the filtrate and the chemistry was completed as shown in Fig. 5. Tracers were not added to this chemistry. However, the yield of Au, Hg and Bi tracers in the CuS acid solution was typically greater than 80% in identical practice separations. The yield for Pb was about 60% while the yield for Ir was as low as 20%. The majority of the Pb was recovered in the CuS-base fraction because of incomplete precipitation from 2 M HCl as expected [19]. The precipitates were designed to give less than 10 MeV energy loss for a typical fission fragment emitted at 45^{o} to normal, from the bottom of the sample. The CuS samples were placed on small discs and held within a millimeter of the sensitive face of the surface barrier detectors. This facilitated a detection efficiency, for alpha particles, between 25% and 30%. The CuS-acid and CuS-base samples were counted continuously for alpha and SF events for 60 and 90 days respectively. The CuS precipitates should have contained SHE's that formed insoluble sulfides or that may have been reduced to the zero oxidation state and were carried with the precipitate. It is conceivable that SHE's that are very volatile and noble would have been lost by both chemistry schemes. However, any SHE that formed a volatile bromide complex that might have gone undetected in Scheme I would have been observed in Scheme II. The LaF_3 sample was also counted for alpha activity. Radium as well as the lanthanide and actinide elements will precipitate quantitatively under these conditions.

B. Recoil Experiments

Several preliminary experiments (labeled SF1, SF2 and SF3 in Table 2) were carried out by catching the recoiling reaction products in a stack of 8 or more 200 $\mu g/cm^2$ aluminum foils placed in position B of Fig. 2. These bombardments were of relatively short duration at average beam levels of 4×10^{11} particles per sec. The foils were removed from the target-recoil catcher assembly and counted directly for SF events in windowless 2π gas proportional counters. Typically, counting began within 5 minutes of the end of the bombardments. The first foil showed SF activity (which did not decrease over the course of the experiment) that was presumed at the time to be from thermal transfer of some of the ^{248}Cm target nuclei. This foil then was treated as a protective foil for those recoil foils behind it. By extrapolation of the range-energy tables [20] as a function of Z, range values were determined for the compound nucleus indicating that the SHE products should be in foils 4 through 7. Low levels of SF activity were found in these foils. The decay was barely discernible due to poor statistics but seemed to be characteristic of the decay of ^{256}Fm from its ^{256}Es parent. A long-lived component possibly from ^{252}Cf and ^{254}Cf was also seen. Later radiochemical studies showed that these isotopes are produced in sufficient yield, perhaps through transfer reactions, to account for the activity levels seen [21].

In the last such experiment (labeled SF4 in Table 2) the recoil foils were moved to position C in Fig. 2 to take advantage of this more restrictive geometry to eliminate the SF interference from

actinides produced in transfer reactions. In this experiment the central foils of the stack, the fourth through seventh foil inclusive, were counted in an approximately 4π geometry between opposed surface barrier detectors for alpha and SF events. The remaining foils were counted only for SF events in the 2π windowless gas counters. Counting of all the collection foils began within eight minutes of the end of bombardment and continued for approximately 21 hours.

RESULTS

The nonvolatile superheavy element fraction from chemistry Scheme I has been counted for over 230 days. Only one coincidence SF event was observed, on the 60th day of counting. The total kinetic energy (TKE) of this event is 215 MeV which, although significantly larger than the most probable TKE for SF of ^{248}Cm, cannot be excluded from the energy distribution of fragments from the SF of an actinide element (see Fig. 4). Four other non-coincident events were also observed. Three of these events have energies between 50 and 60 MeV and one has an energy of 138 MeV. There has been no indication of any decay associated with these events.

The CuS-acid sample and CuS-base sample (Scheme II) have shown no fission counts over the period these samples have been counted (60 and 90 days). And finally in the direct counting of the central Al recoil collectors (SF4) three coincident and one non-coincident fission event have been seen. These three events have an average measured TKE of 161 MeV. The average measured TKE for the SF of ^{248}Cm under

identical conditions is 158 MeV. Thus the four events observed in this work could very well be due to actinide element SF decay.

As a summary of our results, Fig. 6 shows the upper limit cross sections for the formation of SHE's 108-116 plotted as a function of the assumed half-life of the SHE's. The variation in cross sections is a result of bombardment saturation effects for the short half-lives and incomplete decay for the half-lives comparable in length to the total counting time. In Fig. 7 we have combined the results of these experiments with those of A. Ghiorso et al. for the same reaction but whose emphasis was on shorter half-life species [22].

From the alpha spectrum obtained by counting the various samples from chemistry Scheme II, production cross sections for some of the isotopes between Pb and Th have been calculated and are given in Table 3. The cross sections for ^{210}Po, ^{211}At and ^{213}Bi are really summations of the formation cross sections of all the short-lived elements in the alpha decay series leading to these final products. The cross section for ^{213}Bi, however, was corrected for growth and decay of ^{225}Ra and ^{225}Ac that occurred prior to the counting period.

CONCLUSIONS

It is apparent that the small number of SF counts observed in our SHE chemical fractions can be accounted for by the presence of extremely small quantities of actinide isotopes in these chemical fractions or by background SF counts. Thus our results indicate the absence of SHE of half-lives and production cross sections that would

be detectable under the conditions of our experiments. A possible exception to these negative results is the SF event observed with TKE 215 MeV because such a large energy would be observed in less than 1% of the events that might arise from the SF decay due to any known actinide nuclide (see Fig. 4).

On the assumption that our results should be accepted as negative, we can suggest a number of explanations for our inability to detect SHE. Perhaps the most likely of these are: (1) the half-lives may be too short or too long to have been detected; (2) the production cross sections are actually below the limits set by our experiments; and (3) less likely, the actual chemical properties of the SHE's are very different than the predicted properties.

With respect ot the first possibility, Figs. 6 and 7 show that cross sections as large as a nanobarn (10^{-33} cm) could not have been observed for half-lives less than a few minutes and longer than about three years. Thus a large region of possible half-lives remains unexplored with sensitivity corresponding to a cross section of about a nanobarn.

According to the second possibility, the actual production cross sections might be smaller than our sensitivity limits, as expressed in Figs. 6 and 7, even including the range of half-lives explored in our experiments. When a compound nucleus is formed, the emission of neutrons (and gamma-rays) to form the desired ground state of the SHE must compete with fission. For this reason, we wish to have a minimal number of neutrons emitted in order to restrict as much as

possible the loss due to fission at each stage of neutron emission. The predicted values of Γ_n/Γ_f in the SHE region (in this case the compound nucleus $^{296}116$) are very small so that we presumably cannot afford to have more than two neutrons emitted, e.g., the ^{48}Ca, 2n reaction is our objective. It seems likely that our excitation energy for the compound nucleus of about 40-50 MeV is too large to optimize the 2n reaction. This difficulty is apparently compounded because in this region the predicted ground state fission barriers are dropping by approximately 1 MeV for each neutron evaporated [2,6]. Although the cross section for the fusion reaction with ^{48}Ca ions is somewhat smaller than might have been expected, there is apparently a sufficiently large cross section to produce a compound nucleus in appreciable yield. (Mass distribution studies of the reaction of ^{48}Ca with ^{208}Pb [24] show that the complete fusion cross section is a factor of $\sim$2 less than would be expected based on ^{40}Ar reaction studies [4,5].) Also in our favor is the higher survival probability of the more neutron rich and minimally excited nuclides formed with ^{48}Ca. Ghiorso et al. have found the cross section for the reaction $^{208}Pb(^{48}Ca,2n)^{254}No$ to be about 3 microbarns, whereas the cross section for the reaction $^{208}Pb(^{40}Ar,3n)^{245}Fm$ was found to be about 15 nanobarns [25].

The third possibility might be that grossly incorrect predictions have been made concerning the chemical properties of the SHE. However, it seems unlikely that the chemical properties of the SHE could be very different than those predicted. The relatively basic assumptions about the chemical properties of the SHE's and the

precautions taken to allow for wide variations in the reduction potentials, volatility and complexing strength of the SHE's provides some assurance that any SHE's produced would have been recovered in at least one of the samples. Only very volatile noble metal SHE's or SHE's with chemical properties much different than their lighter homologs could have conceivably remained unidentified.

ACKNOWLEDGMENTS

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REFERENCES

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1. W. D. Myers, W. J. Swiatecki, Nucl. Phys. 81, 1 (1966).
2. E. O. Fiset, J. R. Nix, Nucl. Phys., A193, 647 (1972).
3. W. J. Swiatecki, C. F. Tsang, LBL-666, p. 138, 1971.
4. J. V. Kratz, J. O. Liljenzin, A. E. Norris, G. T. Seaborg, Phys. Rev. C13, 2347 (1976).
5. F. Hanappe, C. Ngo, J. Peter, B. Tamain, Proceedings of the Third Symposium on the Physics and Chemistry of Fission, Rochester, 1973.
6. W. D. Myers, W. J. Swiatecki, UCRL-11980 (1966), and private communication (1976).
7. C. F. Tsang, LBL-2366, p. 146, May 1974.
8. W. J. Swiatecki, private communication.
9. G. T. Seaborg, Ann. Rev. Nuc. Sci. 18, 53 (1968).
10. J. V. Kratz, J. O. Liljenzin, R. J. Silva and G. T. Seaborg, LBL-1666, p. 308 (1972).
11. F. David, Institute de Physique Nucleaire, Orsay, Report R6-71-06 (1971) UCRL Trans 10641.
12. O. L. Keller, Jr., J. L. Burnett, R. A. Carlson and C. W. Nestor, Jr., J. Phys. Chem. 74, 1127 (1970).
13. O. L. Keller, Jr., C. W. Nestor, Jr., and B. Fricke, J. Phys. Chem. 78, 1945 (1974).
14. O. L. Keller, Jr., C. W. Nestor, Jr., T. A. Carlson and B. Fricke, J. Phys. Chem. 77, 1806 (1973).
15. K. S. Pitzer, J. Chem. Phys. 63, 1032 (1975).

16. J. V. Kratz, J. O. Liljenzin, G. T. Seaborg, Inorg. Nucl. Chem. Lett. 10, 951 (1974).

17. M. M. Fowler, R. C. Jared, Nucl. Inst. Meth. 124, 341 (1975).

18. M. P. Spivack, The Review of Scientific Instruments 43, 7 (1972).

19. V. J. Moore, Analyst, 81, 533 (1956).

20. L. C. Northcliffe, R. F. Schilling, Nucl. Data A7, 233 (1970).

21. E. K. Hulet et al., submitted for publication in Phys. Rev. Lett.

22. A. Ghiorso et al., private communication.

23. A. Ghiorso et al., Phys. Rev. Lett. 33, 1490 (1974).

24. D. J. Morrissey, R. J. Otto, W. D. Loveland and G. T. Seaborg, submitted for publication in Phys. Rev. Lett.

25. A. Ghiorso, J. M. Nitschke, R. E. Leber, unpublished data (1976).

TABLE HEADINGS

Table 1. Calculated Q Values and Excitation Energies for the Reaction $^{48}Ca + ^{248}Cm$.

Table 2. Summary of $^{48}Ca + ^{248}Cm$ Experiments.

Table 3. Production Cross Sections for Alpha Emitting Isotopes Obtained from Chemistry Scheme II.

Masses from	Fiset Nix [2]	Myers Swiatecki [1,6]
Q Value (MeV)	-164	-170
	Excitation Energy (MeV)	
(a) 233 MeV ^{28}Ca (B_{Lab})	∿31	∿25
(b) 255 MeV ^{48}Ca (avg E_{Lab})	∿50	∿43

Experiment	Length of Bombardment (hrs.)	Total Integrated Beam (Atoms ^{48}Ca)	Geometry[a] (Recoil Foils)
SF1[b]	1.3	7.8×10^{14}	B (8×232 μg/cm^2 Al)
SF2	3.7	3.2×10^{15}	B (8×230 μg/cm^2 Al)
Radiochemistry (Scheme I)	24.8	4.9×10^{16}	B (2.2 mg/cm^2 Be)
SF3	.75	2.9×10^{15}	C (14×234 μg/cm^2 Al)
SF4	11.9	9.3×10^{15}	C (14×200 μg/cm^2 Al)
Radiochemistry (Scheme II)	12.0	1.7×10^{16}	A (18×200 μg/cm^2 Al)

[a] The letters A, B, C refer to positions in Fig. 2.

[b] "SF" indicates a stacked foil experiment in which the foils were counted for spontaneous fission events directly.

Parent Isotopes and (Half-Life)	Observed Alpha Energy in MeV and (Nuclide)	Cross Section in μbarns
^{213}Bi (45.6m)	8.375 (^{213}Po)	129 ± 30[a]
^{210}Po (138.38d)	5.305 (^{210}Po)	742 ± 167
^{211}At (7.2h)	7.450 (^{211}Po)	128 ± 29
^{223}Ra (11.43d)	7.386 (^{215}Po)	54 ± 12[b]
^{224}Ra (3.64d)	8.784 (^{212}Po)	35 ± 8
^{225}Ac (10.0d)	8.375 (^{213}Po)	155 ± 35[c]

[a] Corrected for growth and decay of ^{225}Ac and ^{225}Ra.

[b] Production cross section not corrected for growth and decay of ^{227}Th.

[c] Production cross section not corrected for growth and decay of ^{225}Ra.

FIGURE CAPTIONS

Fig. 1. (a) Schematic representation of the positions of the beam collimator, target assembly, Au scattering foil and magnetically protected Faraday cup used in the first phase of this work. The energy of elastically scattered ^{48}Ca ions was measured by a surface barrier detector at 16^{o} to the beam axis.
(b) In the second part of the work the collimator and target assembly were moved behind the scattering foil to facilitate constant energy monitoring of the beam.

Fig. 2. An expanded schematic view of the target assembly showing the relative positions and geometries subtended by the recoil collection foils.

Fig. 3. Flow diagram for the first chemical separation procedure used (Scheme I).

Fig. 4. TKE spectrum from the ^{252}Cf calibration. Also shown is the position of the 215 MeV TKE event seen in the first radiochemistry experiment. (Scheme I).

Fig. 5. Flow diagram of the second chemical separation, based on precipitation of insoluble sulphides. (Scheme II).

Fig. 6. Upper limit cross sections for SHE's 108-116 plotted versus half-life from this work. The curve labeled SF4 is based on the direct counting experiments. Curves labeled Chem I and Chem II are based on the result of the radiochemistry Schemes I and II respectively.

Fig. 7. The upper limit cross section results of experiments by Ghiorso et al. [22] for the same reaction are plotted along with the results of this work shown in Fig. 6. The curve labeled DIF (Decay in Flight experiments) is based on the results from mica track detector experiments designed to detect fission fragments originating from recoil SHE nuclei, on the time scale that it would take these nuclei to stop in He gas. The curve labeled VW (Vertical Wheel experiments) is based on the results of a gas jet experiment employing the same techniques used in the discovery of element 106 [23].

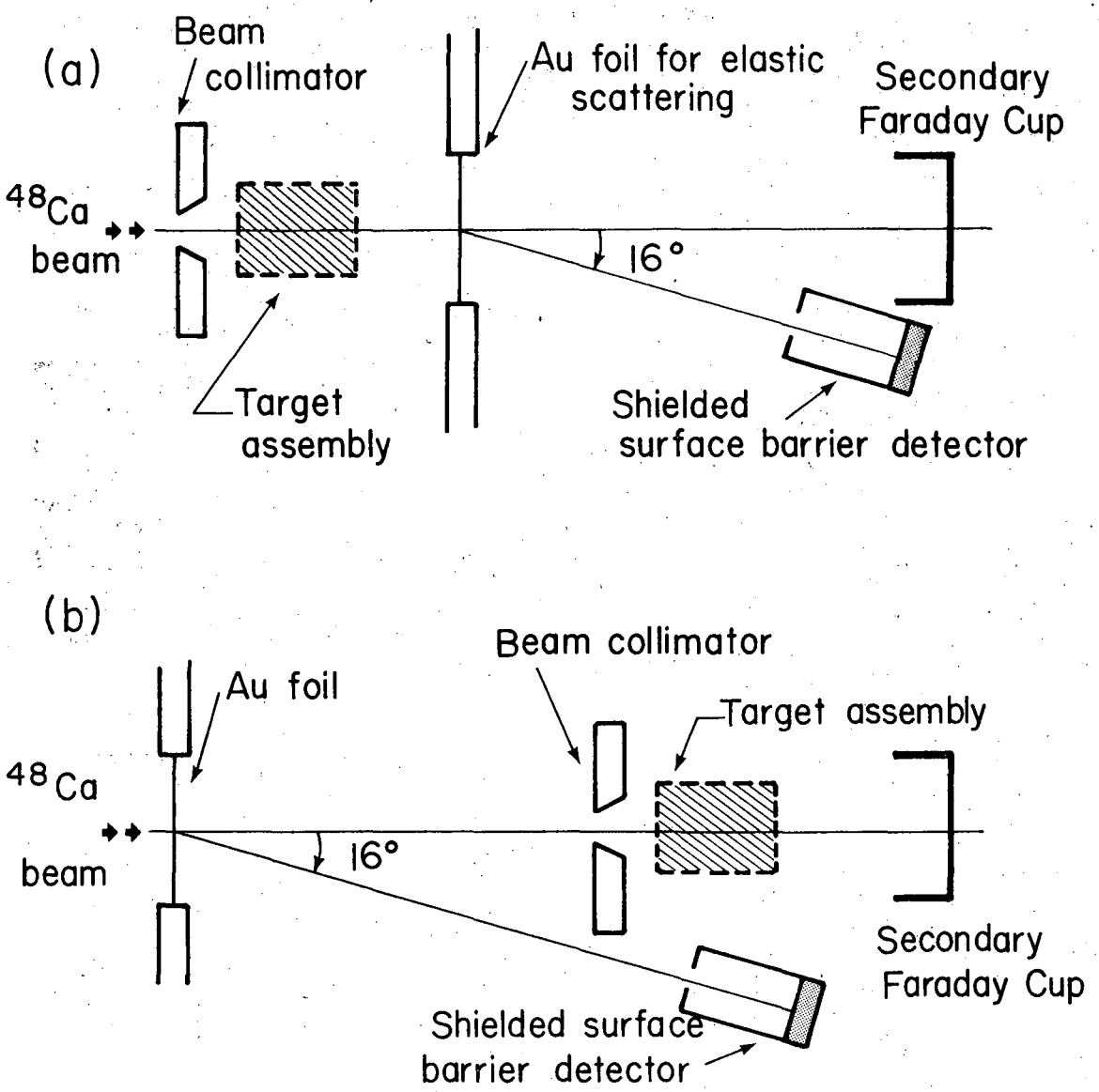
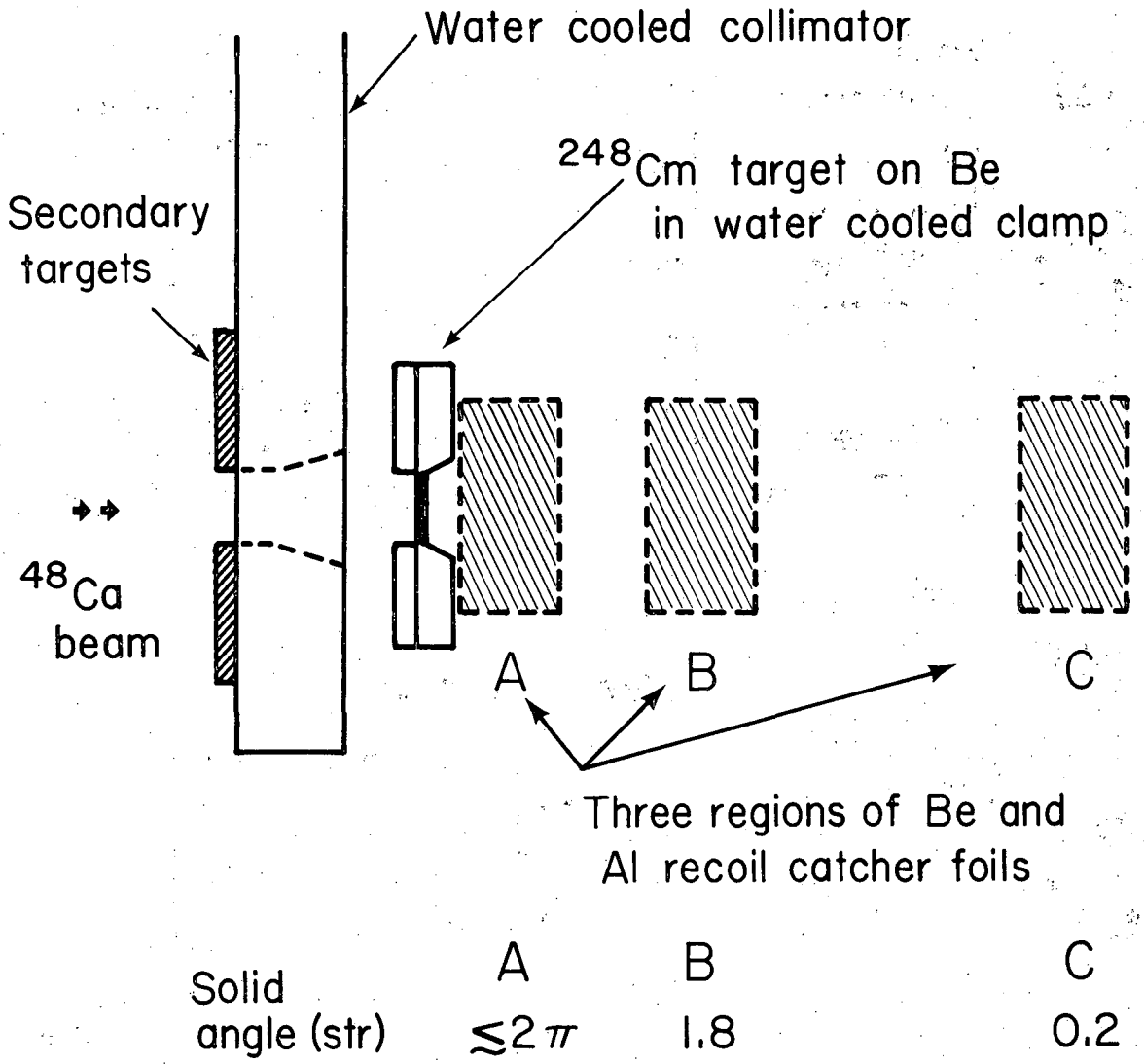

(a)
Beam collimator
Au foil for elastic scattering
Secondary Faraday Cup
48Ca beam
16°
Target assembly
Shielded surface barrier detector
(b)
Beam collimator
Au foil
Target assembly
48Ca beam
16°
Secondary Faraday Cup
Shielded surface barrier detector
XBL775-1030

Fig. 1



Solid angle (str)	A	B	C
	$\lesssim 2\pi$	1.8	0.2

XBL775-1031

Fig. 2

RADIOCHEMISTRY SCHEME I

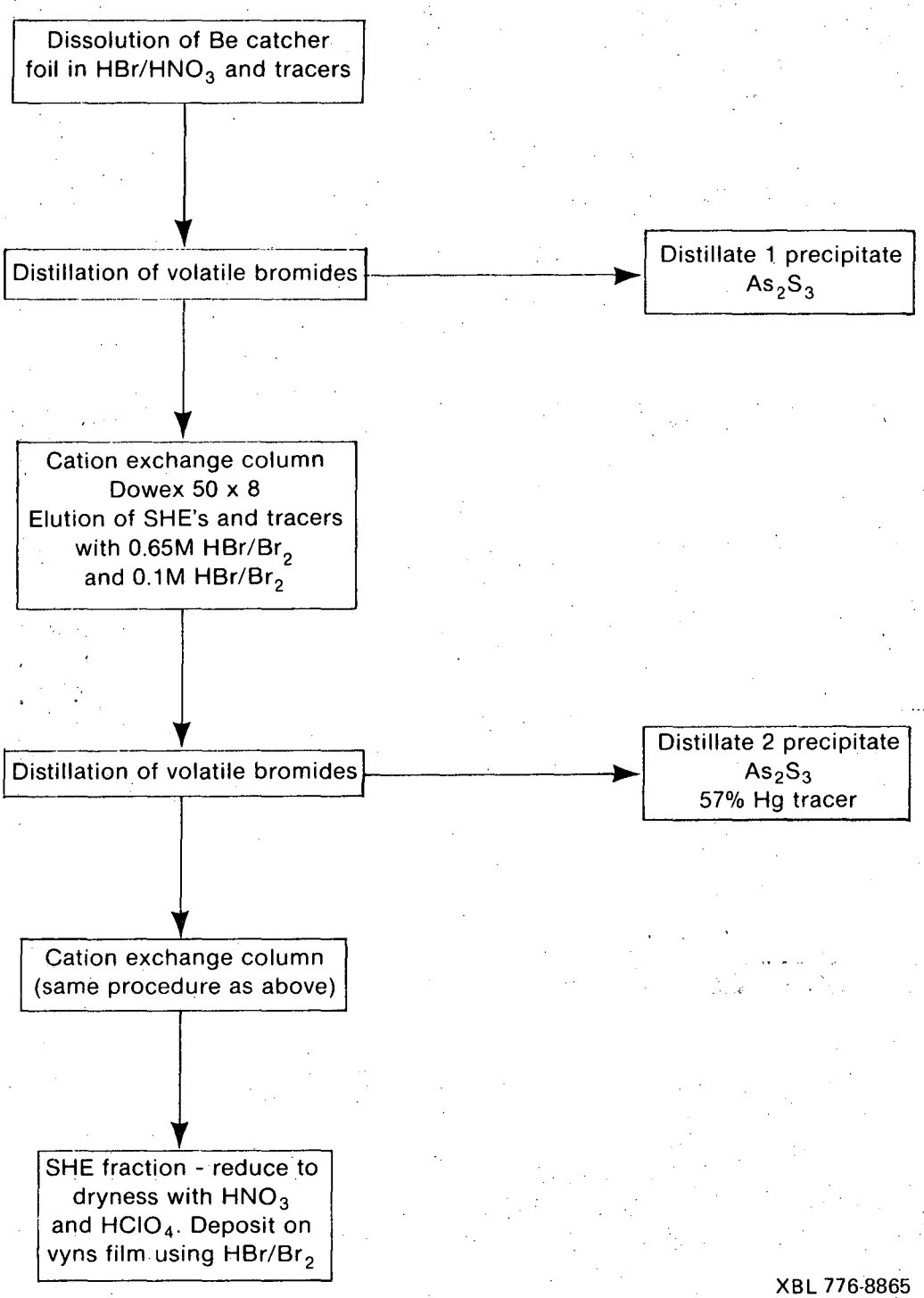


Fig. 3

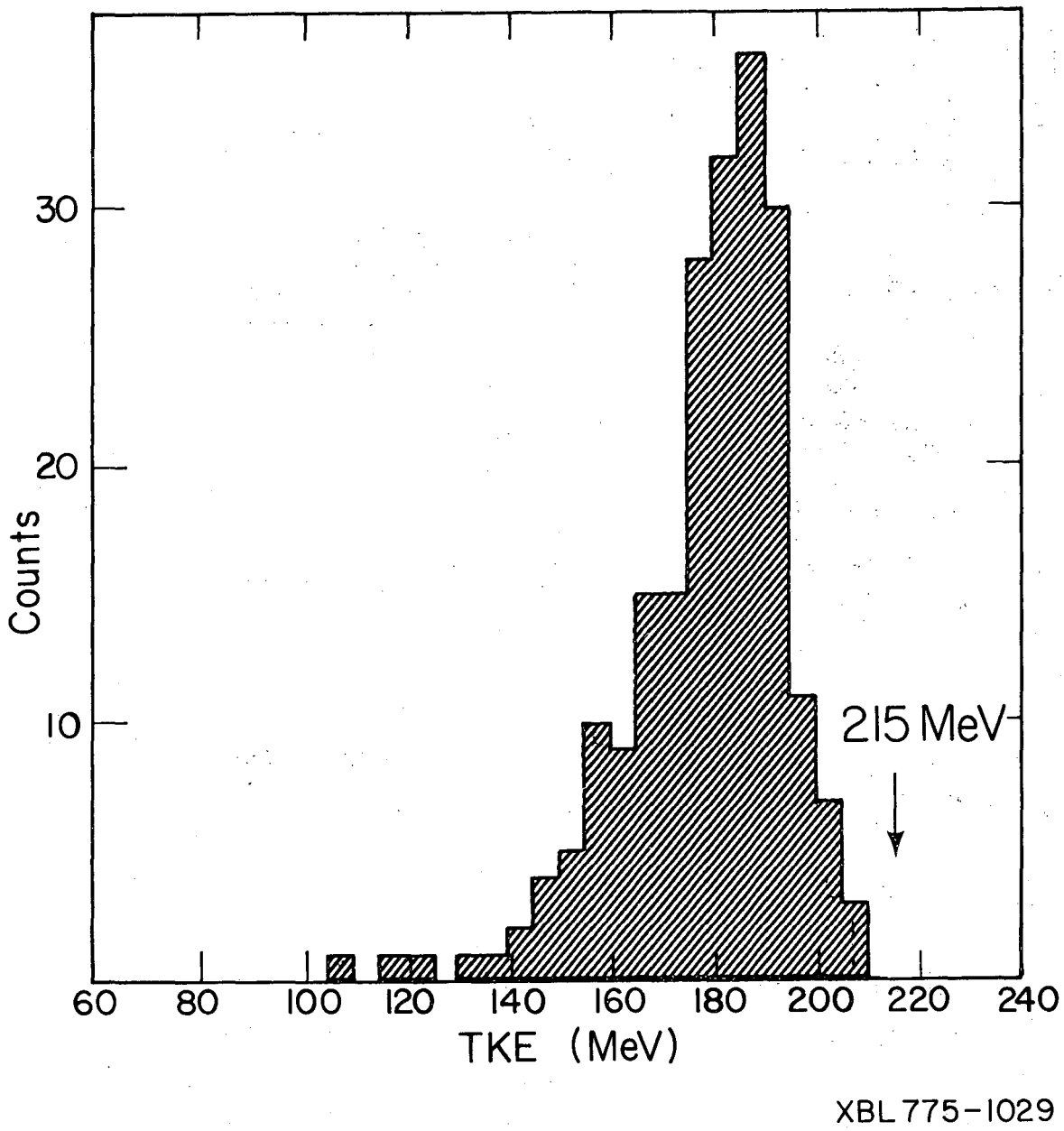

30
20
10
Counts
215 MeV
60
80
100
120
140
160
180
200
220
240
TKE (MeV)
XBL 775-1029

Fig. 4

RADIOCHEMISTRY SCHEME II

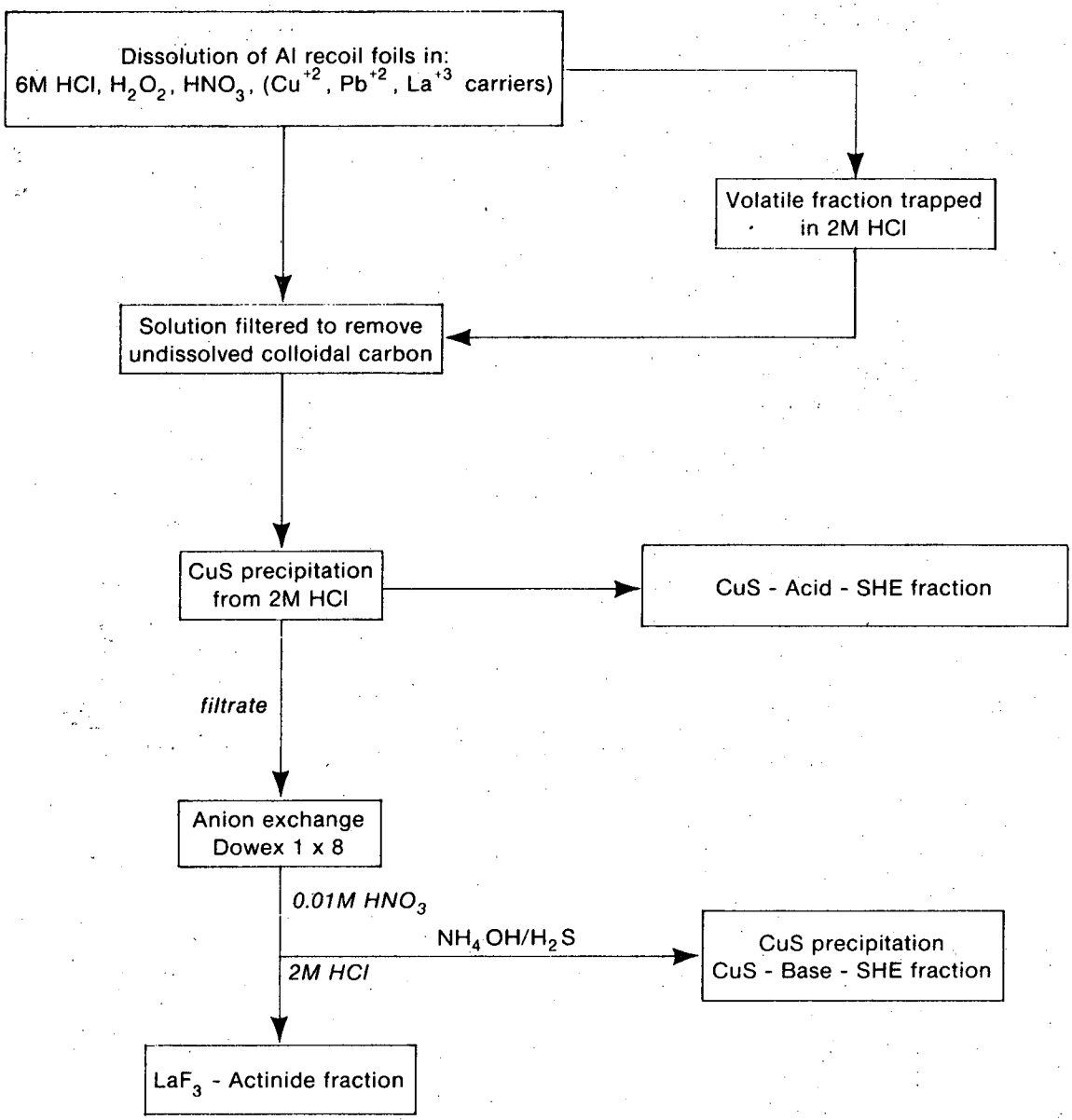
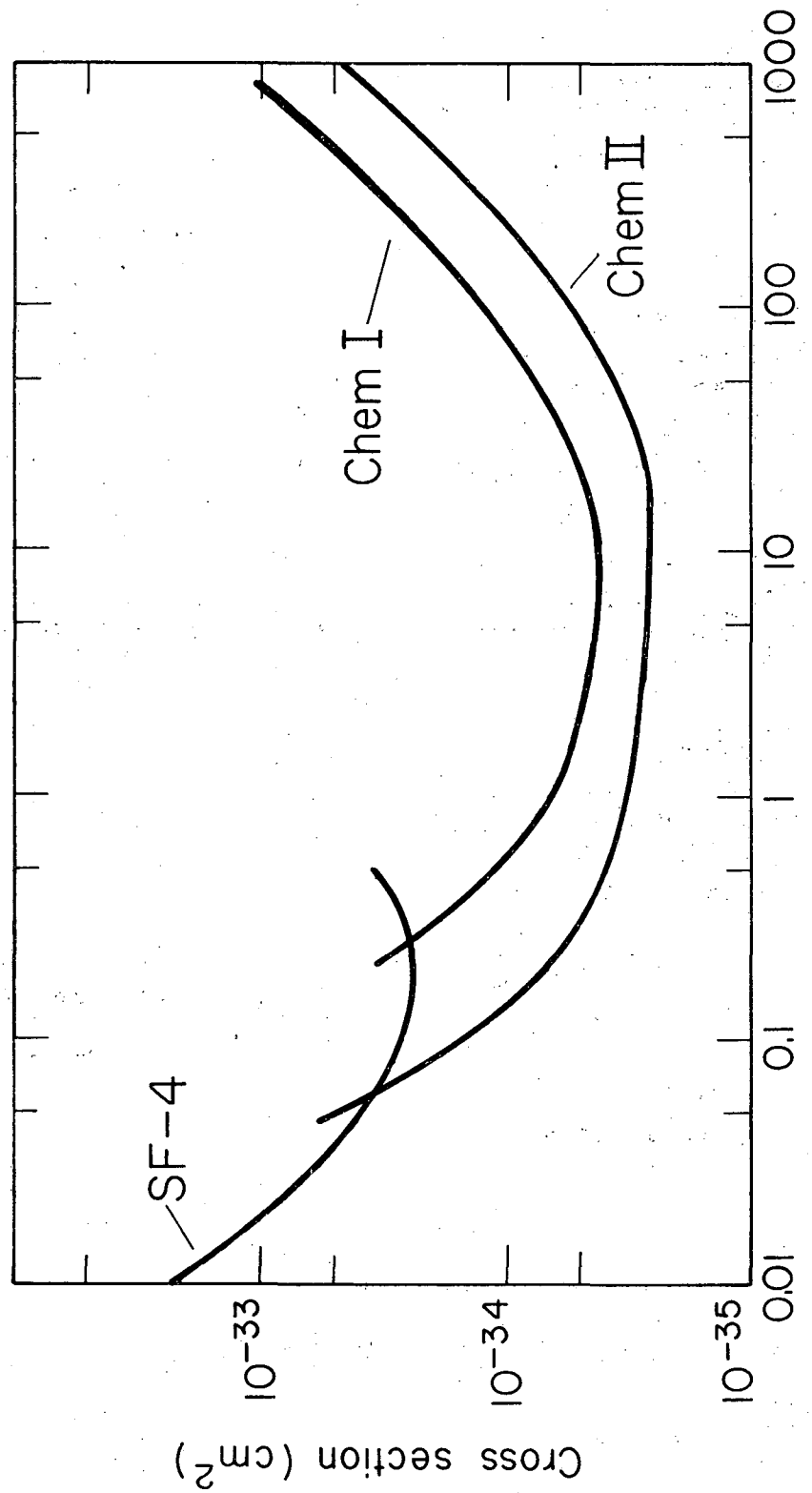


Fig. 5



XBL 775-1033

Fig. 6

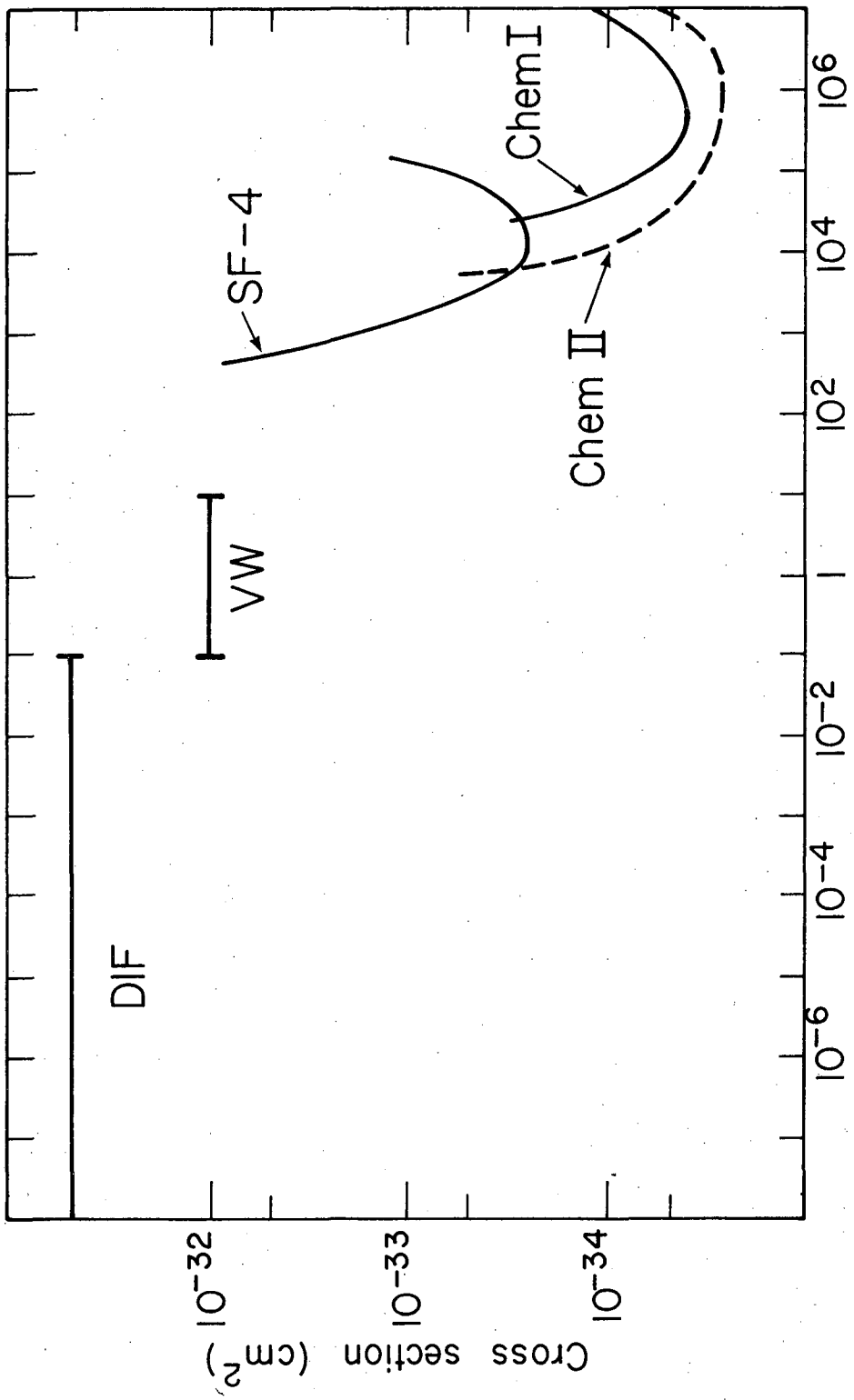


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Fig. 7

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