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# RECENT STUDIES OF THE NUCLEAR AND CHEMICAL PROPERTIES OF ELEMENTS 103, 104, AND 105

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Information obtained since 1983 on the nuclear and chemical properties of element 103, the last of the actinide series, and elements 104 and 105, at the beginning of the transactinide series, is reviewed. Their chemical properties are compared with their lanthanide and lighter group 4 and 5 homologs and evidence for possible relativistic effects is discussed. The current knowledge of the nuclear properties of these elements and how these affect the study of chemical properties is discussed. Some of the challenges involved in the study of short-lived isotopes which can only be produced an "atom-at-a-time" at an appropriate accelerator and the prognosis for future studies of these and still heavier elements are considered.

# RECENT STUDIES OF NUCLEAR AND CHEMICAL PROPERTIES OF ELEMENTS 103, 104, AND 105

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## I. Introduction

Results of recent experiments, since the 1983 review of Hulet (1), to determine the nuclear and chemical properties of element 103 (Lr), the last of the actinides, and elements 104 (Rf), and 105 (Ha), the beginning of the transactinides, will be discussed. Comparison of even rudimentary chemical behavior, such as the most stable oxidation states and complexing ability, of these elements with their lighter homologs is important in establishing the validity of predictions based on extrapolation of trends shown in a given family of the periodic table. Knowledge of the chemical behavior is also important in assessing the influence of relativistic effects in these very heavy elements. Information about nuclear properties is essential for these studies and is vital in understanding nuclear stability at the upper end of the periodic table. The known isotopes of elements 104 and 105 are all very short-lived, have small production cross sections (often nanobarns or less), can only be produced an "atom-at-a-time" at an appropriate accelerator, and must be identified by measurement of their radioactivities. Very fast and efficient radiochemical

procedures and detection techniques are required. Furthermore, in order to obtain reliable information about the chemical properties of these very short-lived species, chemical procedures in which each of the available atoms undergoes rapid equilibration through many reactions must be used. Ion exchange, solvent extraction, and gas chromatography are examples of such procedures. Some of the challenges and difficulties involved in these studies and the unique facilities and capabilities which are required will be discussed as the current knowledge about each of these elements is reviewed.

## II. Element 103, Lawrencium (Lr)

### A. Nuclear Properties

The first isotope of lawrencium to be discovered (2) was the 8.6-MeV alpha-emitter, $^{257}$Lr, with a half-life of 4.3 seconds. By 1983, eight isotopes of Lr had been reported (3). However, 3-minute $^{260}$Lr, discovered by Eskola et al. (4) in 1971, remained the longest known isotope until the very recent discovery of 40-minute $^{261}$Lr and 3.6-hour $^{262}$Lr reported by an LLNL-LBL collaboration (5, 6) led by R. W. Lougheed. The rare, radioactive target $^{254}$Es (available in quantities of only 5 micrograms or less) was used to prepare these new, neutron-rich isotopes with the rather large cross sections of 240 nanobarns and 37 nanobarns, respectively, via transfer reactions with $^{22}$Ne projectiles from the Lawrence Berkeley Laboratory (LBL) 88-Inch Cyclotron. Positive assignment of atomic number (Z) was accomplished by careful radiochemical separations using the well known elution from a cation exchange

column with ammonium alpha-hydroxyisobutyrate solutions. Mass assignments were made by mass separation in an electromagnetic separator of chemically separated Lr fractions. The nuclear properties of these two new isotopes were also carefully examined. No alpha activity attributable to either isotope was observed and a limit of ≤20% was estimated for this decay mode. Spontaneous fission (SF) decay of $^{261}$No was not observed in No samples separated radiochemically from Lr in about 10 minutes, indicating either that the SF half-life of $^{261}$No is much less than 10 minutes, or that its SF half-life is much longer than 10 minutes and that it probably decays primarily by some other decay mode. The first possibility was judged unreasonable since the SF half-life of $^{259}$No is much longer than 10 minutes and $^{261}$No would be expected to be still longer. Therefore, it was concluded that $^{261}$Lr decays primarily by SF (>80%) and the observed 40-minute SF activity was attributed to $^{261}$Lr. In repeated very careful radiochemical separations of Lr, followed by electroplating on very thin films, it was possible to make measurements (6) of the time intervals between No K x-rays and subsequent SF events and show that $^{262}$Lr decays via electron capture (>50%) to $^{262}$No which then spontaneously fissions. These experiments permitted the measurement of the half-life of $^{262}$No as 5 milliseconds and the mass and kinetic-energy distributions for its SF were determined from the measurement of the kinetic energies of coincident fission fragments. $^{262}$No has 160 neutrons, the most for any nuclide known, to date, so its SF properties are of particular interest. Its SF shows a narrowly symmetric mass distribution (FWHM=12 mass units),

but its total kinetic-energy (TKE) distribution shows a "bulge" on the low energy side and can be fit with two Gaussian components of about 200 MeV (35%) and 237 MeV, (65%). This "bimodal" distribution is similar to those recently reported by Hulet et al. (7) for $^{258}Fm$, $^{259}Md$, $^{260}Md$, and $^{258}No$. It implies the existence of two modes of symmetric fission, one in which deformed fragments with low total kinetic energy (TKE) are formed, and the other in which spherical fragments near the doubly magic $^{132}Sn$ configuration with consequently high TKE are formed. Its SF half-life of $^{262}No$ of 5 ms is several orders of magnitude longer than recent theoretical estimates.

The spontaneous fission half-lives of the $^{261}Lr$ and $^{262}Lr$ of about 40 minutes and greater than 36 hours (3.6 hours, <10% SF) indicate hindrance factors of $>10^4$ to $>10^7$ relative to their even-even neighbors. This supports previous observations (8) that an odd proton, in this case Z=103, or an odd neutron can greatly lengthen SF half-lives, often by factors of as much as $10^5$. (See Fig. 1.) Nuclides with both an odd proton and an odd neutron appear to be hindered by even larger factors, as illustrated by the odd-odd nuclide $^{262}Lr$ which was found to decay predominantly by electron capture. These findings make the discovery of longer-lived, more neutron-rich isotopes of the odd-Z elements 107 and 109 appear particularly promising if methods for producing them with sufficiently large cross sections can be devised.

B. Chemical Properties

Early studies (9) of the extraction behavior of Lr were conducted using 26-second $^{256}Lr$ and showed that Lr(III) was the most stable oxidation state in aqueous solution. However, even though 3-minute $^{260}Lr$ was identified in 1971, no further chemical experiments were performed on Lr until those of Hoffman et al. (10) reported in 1987. TTA (thenoyltrifluoroacetone) extractions, similar to those of Silva et al.(9), were performed manually to show that the 3-minute, 8.03-MeV Lr alpha activity produced via the $^{249}Bk(^{18}O, \alpha, 3n)$ reaction was indeed properly assigned to Lr. The production cross section was measured to be 8.3 ± 1.7 nanobarns. Repeated manual experiments in which Lr was eluted from a cation-exchange resin column with ammonium alpha hydroxyisobutyrate were performed in order to infer the ionic radius of Lr by comparison of its elution position with the elution positions of rare earth tracers and actinides of known radii. Lr was found to elute nearly the same position as Er tracer. Based on subsequent comparisons of the elution position of only 7 alpha events of $^{260}Lr$ with the elution positions of the rare earth tracers Tm and Ho, an average ionic radius of 0.0886 ± 0.0003 nm was calculated for Lr, assuming the ionic radius of Er is 0.0881 nm as measured by Templeton and Dauben (11). This result was somewhat surprising because it gives a difference of only 0.001 nm for the 2Z difference between Md (0.0894 nm) and Lr. This is much smaller than the 2Z separation of 0.0021 nm for the anaologous trivalent lanthanide ions, Tm and Lu. In later experiments, also conducted at the 88-Inch Cyclotron at LBL, a

German-American collaboration (12) used the automated system, mini-ARCA (Automated Rapid Chemistry Apparatus) to check this unexpected result and improve its statistical significance. Again, Lr was found to elute nearly with Er and Md eluted nearly with Ho. (See Fig. 2). The log $K_d$ values obtained from the elution positions of the trivalent Tm, Er, and Ho for coordination number 6 correlate linearly with the crystallographic radii of Templeton and Dauben (11) as do the values for trivalent Es and Cf and the ionic radii reported by Haire and Baybarz (13). From this correlation, the log $K_d$ values for trivalent Fm, Md, and Lr indicate that the ionic radius of Fm is 0.0016 nm smaller than that of Es, a 1% separation. The measured distribution coefficients were used to obtain ionic radii of 0.0881 ± 0.0001 nm for Lr and 0.0896 ± 0.0001 nm for Md. This confirmed the small separation of only 0.0015 nm between them, even though there is a 2% difference. This small difference suggests that the contraction at the end of the actinide series is relatively stronger than at the end of the lanthanide series. Using these radii and semi-empirical models, heats of hydration of -3654 kJ/mol and -3685 kJ/mol were calculated for trivalent Md and Lr, respectively.

In companion experiments (14), attempts were made to reduce $Lr^{3+}$ to see if perhaps there is sufficient stabilization of the $7s^2$ electronic orbitals by relativistic effects so that only a single electron is removed under reducing conditions, thus permitting preparation of $Lr^{1+}$ or $Lr^{2+}$ in aqueous solution. A hydrogen di(2-ethylhexyl)orthophosphoric acid (HDEHP) chromatographic column

separation, again using mini ARCA (15), was devised to separate the $1^+$ and $2^+$ states from the $3^+$ state. In a series of experiments using $V^{2+}$ and $Cr^{2+}$ in dilute HCl as reducing agents, $Md^{3+}$ was reduced to $Md^{2+}$ ($E^o$=-0.2 V), but there was no evidence for reduction of $Lr^{3+}$ to either the $1^+$ or $2^+$ oxidation state. From these data, the limit for the reduction potential of the $Lr^{3+}/Lr^{1(2)+}$ couple was calculated to be < -0.44 V. In later experiments, Lougheed et al.[16] used the newly discovered 3.6-hour $^{262}Lr$ to try to reduce Lr with $Sm^{2+}$ ($E^o$=-1.55 V) and coprecipitate $Lr^{1+}$ with Rb using sodium tetraphenylborate or chloroplatinic acid, a procedure which takes considerably more time. The $2^+$ and $3^+$ actinides do not precipitate under these conditions and can be physically separated by centrifugation or filtration. From the 20 events observed, they calculated an upper limit (at the 95% confidence level) for the $Lr^{3+}/Lr^{1+}$ couple of -1.56 V and concluded that it is unlikely that $Lr^{1+}$ can exist in aqueous solutions.

On-line gas chromatography has been used (17) to determine if elemental Lr is volatile. Multidimensional Dirac-Fock calculations (18, 19) have predicted that $Lr^0$ should have a ground-state electronic configuration of $[Rn]5f^{14}7s^27p$ instead of $[Rn]5f^{14}6d7s^2$ as expected by analogy with $Lu^0$. Thus, Jost et al. (17) postulated that the volatility of $Lr^0$ might be more like the "p-element" lead, $[Xe]4f^{14}5d^{10}6s^2p^2$ rather than the "d-element", lutetium. However, no evidence for volatility was found under reducing conditions at 1000° C with either quartz or platinum chromatographic columns, but since adsorption on the columns could

possibly promote Lr(p) to Lr(d), the existence of Lr(p) still cannot be excluded.

## III. Element 104, Rutherfordium (Rf)

### A. Nuclear Properties

Isotopes of Rf from 253 through 261 have been reported, but the identity of several (253, 254, 256, 258, 260, and 262) has not been well established (20). These decay by SF with half-lives of tens of milliseconds or less and, therefore, positive identification via chemical separation or the alpha-genetic relationship technique is not possible. This difficulty in unambiguously identifying the species decaying by SF is also the origin of the considerable controversy which has arisen over priority of discovery of element 104. The controversy surrounding the discovery of elements 104 and 105 has been discussed in detail by Hyde, Hoffman, and Keller (21) and will not be discussed here. The isotopes $^{257}$Rf (3.8 seconds) and $^{259}$Rf (3.4 seconds) were produced via $^{259}$Cf($^{12}$, $^{13}$C, xn) reactions and positively identified in 1969 by Ghiorso et al. (22) by detecting their known No daughters. The alpha-emitting, 65-second $^{261}$Rf, which was produced via the $^{248}$Cm($^{18}$O,4n) reaction by Ghiorso et al. (23), still remains the longest known isotope of element 104 and the most attractive for chemical experiments.

The only recent nuclear information for element 104 is on the SF of $^{260}$Rf. Hulet et al. (7) produced a 26±7 ms SF activity in bombardments of $^{249}$Bk with $^{15}$N which they attribute to 20-ms $^{260}$104, based on the agreement of its half-life with previous measurements

(3). They used a fast rotating wheel system to measure the kinetic energies of coincident fission fragments from the recoiling $^{260}$Rf stopped in 100-$\mu$g/cm$^2$ Al foils surrounding the continuously rotating disk. They found that its SF exhibited a broadly symmetric mass distribution with a FWHM of 36 mass units compared to that of only 7.9 for $^{260}$Md. Its TKE distribution was fit with a single low energy component centered around 200 MeV in contrast to the TKE's for $^{258}$Fm, $^{258}$No, $^{259}$Md, and $^{260}$Md which could be fit with two Gaussian components of varying abundances centered around 200 MeV and 234 MeV.

B. Chemical Properties

As pointed out by Hulet (1) in his 1983 review, the chemistry of element 104 has been investigated in the gas phase using the 3-second spontaneously fissioning isotope $^{259}$104. The 65-second $^{261}$Rf was used in aqueous solution studies of the extraction of chloride complexes into trioctylmethylammonium chloride and of elution from cation exchange resin columns with ammonium alpha-hydroxyisobutyrate solutions. The results of these experiments all indicated that Rf possessed a stable tetravalent state and supported its placement in group 4 as part of a 6d transition series with properties similar to the group 4 elements Hf and Zr, members of lighter d transition series.

Very little work on Rf has been reported since then. Relativistic effects were investigated by examining (25) the volatility under reducing conditions of 3-second $^{259}$104 relative to Au, Tl, and Pb in a quartz column at 1170° C. It was found that 104, like Hf and the rare earths, was less volatile than Au, Tl,

and Pb and a sublimation enthalpy of the metallic state much higher than that of Pb and other heavy p-elements was deduced.

Relativistic calculations by Glebov et al. (26), which include 468 jj-configurations, show that the ground state of element 104 should be a J=2 level consisting primarily of the $6d7s^27p$ configuration (80%) with the next nearest level, at 0.5 eV higher energy, consisting primarily of the $6d^27s^2$ configuration (95%). The $7s^27p^2$ is 2.9 eV above the ground state. Thus they conclude that element 104 should indeed belong to the d-elements rather than the p-elements. This is consistent with the current experimental results on its chemical properties.

Our group [Hoffman, D. C., Czerwinski, K. R., personal communication; Gannett et al., (27)] produced 65-second $^{261}Rf$ from the $^{248}Cm(^{18}O, 5n)$ reaction with a cross section of about 5 nanobarns at the LBL 88-Inch Cyclotron and compared its extraction into tributylphosphate (TBP) and tri-iso-octylamine (TIOA) with that of Zr and Hf. In repeated manual separations taking about 1 minute each, the effect of chloride concentration and pH on the extraction of Rf into TBP in benzene and into TIOA in benzene was compared with that of Th, the group 4 homologs Zr and Hf, the group 5 homolog Nb, and trivalent actinides. In general, Rf behaves as a group 4 element and, unlike the trivalent actinides, is extracted efficiently from concentrated HCl. However, at chloride concentrations above 10 M, the extraction of Rf into TBP is lower than that of Zr, Hf, and Th. This may indicate that the chloride complexation is stronger and $RfCl_6^{2-}$ is being formed which does not extract into TBP. However, Rf is nearly 100% extracted

into TIOA from 12 M HCl as are Zr and Nb, while Th and trivalent actinides and lanthanides are very poorly extracted. In future work, studies will be extended to TTA systems to measure the distribution coefficients for Rf. These will be compared with those for Zr, Hf, and Th and should permit calculation of the radius of Rf as well as of thermodynamic quantities.

Recently, Szeglowski et al. (28) have proposed a new rapid technique for studying the solution chemistry of short-lived nuclides. The recoiling reaction products are transported from the irradiation site via a gas transport system and collected on a frit. They are removed with 0.2 M HF and passed through a series of 3 columns containing cation, anion, and cation exchange resins, respectively. This procedure takes about 35 seconds and $^{261}104$ was identified in the column effluents by detection of its granddaughter activity, 3-day $^{253}Fm$, and its electron-capture product, the 20-day alpha-emitter, $^{253}Es$. The solution from the final column was extensively purified and then finally electrosprayed directly onto the surface of a Si/Au detector for alpha spectroscopy. In this way, the behavior of element 104 was inferred based on the detection of several hundred $^{253}Es$ atoms. This showed that 104 in 0.2M HF forms strong anionic complexes which, like Hf complexes, sorb on the anion resin column, but not on the cation exchange resin columns. This confirmed earlier results indicating that Rf is a group 4 transition element. The authors suggest that this method of measuring the element 104 decay products can be used to facilitate detailed studies of the properties of element 104 because the behavior of several hundred

events of element 104 can be measured by detection of its long-lived decay products, in contrast to the tens of atoms of the short-lived 104 species that can be measured directly.

## IV. Element 105, Hahnium (ha)

### A. Nuclear Properties

Isotopes of Ha from 257 through 262 as well as 255 have been reported, but the assignments of 255 and 259 are not well established (20, 29). The longest-lived known isotope is still the alpha-emitting, 35-second $^{262}$Ha which was produced by Ghiorso et al. in 1971 (30) via the $^{249}$Bk($^{18}$O,5n) reaction. Attempts to produce still heavier isotopes have so far been unsuccessful. After chemical separation, the SF branch of $^{262}$Ha was measured by Gregorich et al. (31) to be only 50%, one-third as large as that measured in earlier on-line experiments (30, 32, 33). This indicates the presence of another SF activity of similar half-life which does not belong to element 105. Attempts have been made to measure the fission properties of $^{262}$105 without any chemical separation, but the results are inconclusive due to the interference of SF from 2.6-hour $^{256}$Fm produced in transfer reactions between the $^{249}$Bk target and $^{18}$O projectiles used in the production of $^{262}$Ha.

### B. Chemical Properties

From their gas phase experiments on 2-second $^{261}$105 using thermochromatographic techniques to determine the volatilities of the chlorides and bromides, Zvara et al. (34, 35) concluded that element 105 is a homolog of Nb and Ta. However, because only SF

activity was detected, it is not assured that the detected fissions belonged only to 105. For example, Keller and Seaborg (36) and Hyde et al. (21) interpret the results for the bromides as indicating that Ha behaves more like Hf, a group 4 element, than like the group 5 elements, Nb or Ta. Thus it was of interest to examine the aqueous chemistry of Ha, and in 1987 Gregorich et al. (31) performed the first aqueous chemistry on element 105 using 35-second $^{262}$Ha produced via the $^{249}$Bk($^{18}$O, 5n) reaction at the 88-Inch Cyclotron at LBL. Positive identification was obtained by measuring the energy and time distribution of the alpha decay and by detection of time-correlated pairs of alpha particles from the decay of $^{262}$Ha and its 4.3-second daughter, $^{258}$Lr. In some 800 manual separations taking about 50 seconds each, the sorption of Ha on glass surfaces after fuming with concentrated nitric acid was compared with tracers of the group 4 elements Zr and Hf and the group 5 elements Nb and Ta produced under similar conditions. Ha was found to adhere to the glass, a property also exhibited by the group 5 elements, but not by Zr and Hf. However, Ha was not extracted into methyl isobutyl ketone from mixed nitric acid/hydrofluoric acid solutions under conditions in which the heavy group 5 element Ta was extracted. In order to investigate the properties of Ha in more detail, in 1988 a large collaboration of German, Swiss, and American scientists performed both aqueous and gas phase studies of $^{262}$Ha at LBL using automated techniques. Some 1600 anion exchange separations to investigate the halide complexation of Ha and its sorption on microchromatographic columns containing TIOA on an

inert support were performed (37) on the minute time-scale using the computer-controlled, automated system ARCA-II. It was found that Ha adsorbs on the columns from 10 M and 12 M HCl/0.02 M HF like the group 5 elements, Nb and Ta and can be stripped along with the TIOA in acetone/0.02 M HF. (See Fig. 3.). Ha is eluted together with Nb and Pa by 4 M HCl/0.02 M HF, unlike Ta which remains on the column. This is in contrast to the sorption behavior of Ha on glass which was similar to that of Ta. In separations of Nb and Pa, shown in the lower part of the figure, Ha split almost equally between the two fractions! Thus, the extraction behavior of Ha appears to be similar to that of the pseudo-group 5 element Pa. As pointed out earlier, Rf also extracts nearly quantitatively into TIOA from 12 M HCl which is different from the pseudo-group 4 element Th which does not extract under these conditions.

Additional investigations of the behavior of Ha at lower HCl concentrations need to be performed. The somewhat unexpected behavior of Rf and Ha in aqueous solution compared to their lighter homologs emphasizes the inadequacy of simple extrapolation of the trends observed within a given group of elements in the periodic table. Apparently, their properties depend on more complex relativistic effects and individual differences due to configuration mixing of the bonding orbitals (38, 39), and are not simple extrapolations of trends inferred from lighter elements.

On-line automated gas-phase chemistry experiments on Ha were also conducted. Gaeggeler et al. (40) investigated the volatility of $^{262}$Ha bromides in isothermal gas chemistry experiments in quartz

columns. A schematic diagram of the apparatus and detection system for alpha particles and SF's is shown in Figure 4. Reaction products were carried via a helium gas transport system and stopped on a quartz wool plug where they were brominated with Br or $HBr/BBr_3$ at 1000°C. The temperature in the oven was varied between 300 and 600°C. Volatile species passed through the oven into a reclustering unit and were transported to a rotating wheel system and collected on thin polypropylene foils for measurement and identification of the volatile alpha and SF activities. The maximum yield of Ha was found between 300 and 400°C while the actinides were not observed until about 500°C, consistent with their expected lower volatility. Based on experiments with $^{99}Nb^{g}$ and $^{166}Ta$, the volatility of Ha bromide is found to be intermediate between that of Nb and Ta bromides.

Much additional research on the properties of element 105 in both the aqueous and gas phase remains to be done in order to clarify the differences and similarities between it and its lighter group 5 homologs as well as Pa. Additional information will also help in assessing the validity of the various calculations of relativistic effects and hopefully stimulate further theoretical efforts and calculations.

## V. Future

Much progress in the study of the nuclear and chemical properties of elements 103 through 105 has been made since the last review in 1983. The prognosis for more detailed studies of the chemical properties of element 103 is especially optimistic

now that the longer-lived isotopes 40-minute $^{261}$Lr and 3.6-hour $^{262}$Lr have been discovered. This assumes, of course, the continued availability of $^{254}$Es targets and high intensity heavy ion beams. However, recent experiments (Henderson, R. A., personal communication) have indicated that these isotopes can also be produced via $^{248}$Cm ($^{18}$O, p,xn), reactions. Although the cross sections are only 700 and 240 pb, respectively, milligram quantities of $^{249}$Bk can be obtained, compared to only micrograms of $^{254}$Es.

It seems likely that longer-lived, more neutron-rich isotopes of elements 104 and 105 exist and can be produced from transfer reactions from heavy ion projectiles to still larger $^{254}$Es targets as outlined in the Large Einsteinium Activation Proposal (LEAP) (41) This would, for example, permit extending the investigations of relativistic effects to studies of the reduction potentials for these elements. Extension of chemical studies to element 106 can be contemplated for the 0.8-second $^{263}$106 even with existing techniques such as the microSISAK system (42) which can be used to perform chemical separations on the second time scale. The major development required is the ability to measure alpha and SF activity without the time-consuming step of evaporation of the resulting solutions. Progress has already been made in passing liquids directly over passivated ion-implanted solid state detectors for assay of alpha activity. It also seems probable that reactions with $^{254}$Es or $^{249}$Bk target can be exploited to prepare species of elements 107 and 109 which may be long enough for chemical studies. For example, the following reactions which

result in products near the postulated region of extra stability around N=162 to 164 appear promising: $^{254}Es(^{18}, ^{16}O, xn)^{268-266}107$; $^{254}Es(^{20,22}Ne, xn)^{270-272}109$; $^{249}Bk(^{20,22}Ne, xn)^{266-268}107$.

Results so far have shown that these studies of chemical and nuclear properties are of utmost importance in elucidating both chemical and nuclear properties which cannot be simply extrapolated from those of lighter elements and isotopes. It can be anticipated that many more surprises are still in store for us in this frontier region of both the periodic table and the chart of the nuclides.

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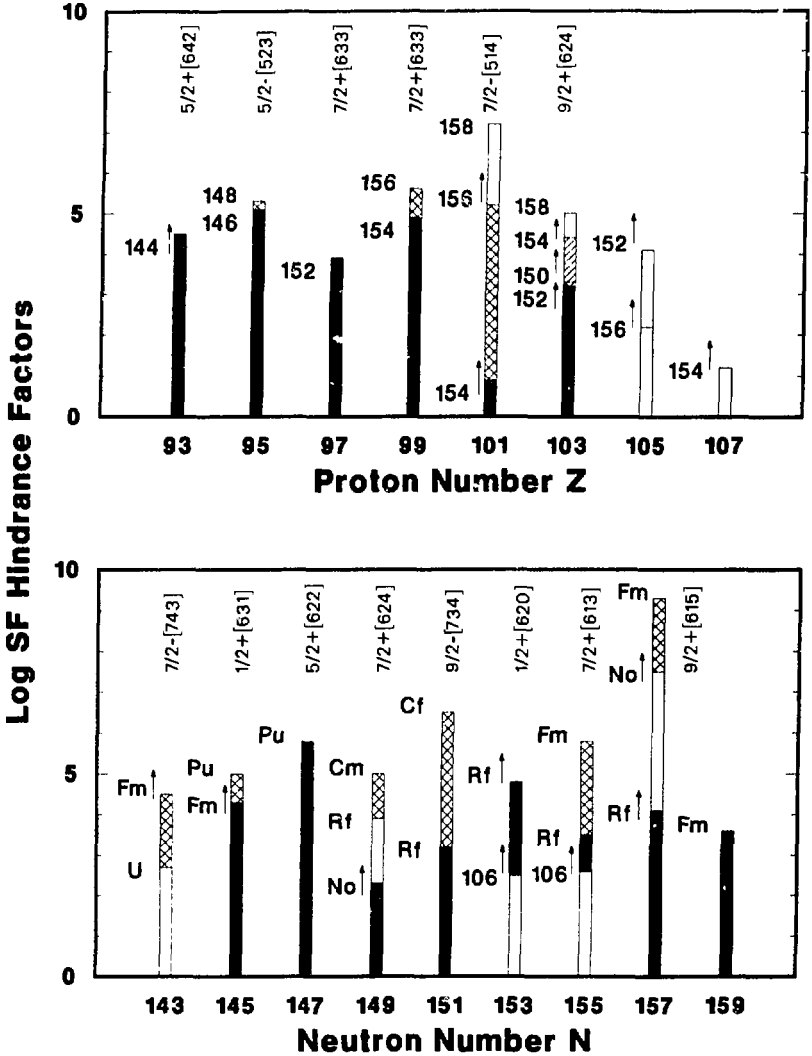
FIGURE CAPTIONS

1. Logarithms of hindrance factors (HF) for SF of odd-neutron and odd-proton nuclides. Arrows indicate lower limit values. An open bar indicates that the HF was calculated relative to only one even-even neighbor (from Ref. 8).

2. Elution of Lr and Md from a cation exchange resin column with ammonium alpha hydroxyisobutyrate compared to elution of Tm, Er, and Ho (from Ref. 12).

3. Elution curves for trivalent actinides, Nb, Ta, and Pa from TIOA columns (1.6 x 8 mm), under the same conditions as for the Ha experiments (from Ref. 37).

4. A schematic diagram of the arrangement used for the gas-phase studies of Ha is shown. The recoiling products from the reaction of $^{18}O$ with $^{249}Bk$ are attached to KCl aerosols and transported in helium gas to the bromination and separation apparatus. After separation, the Ha is again transported via an aerosol-loaded gas jet and deposited on a thin polypropylene disc held on a horizontal wheel that can be rotated so as to position the foils successively between pairs of surface barrier detectors for measurement of alpha and SF activities.




XBL 8911-4221

Fig. 1

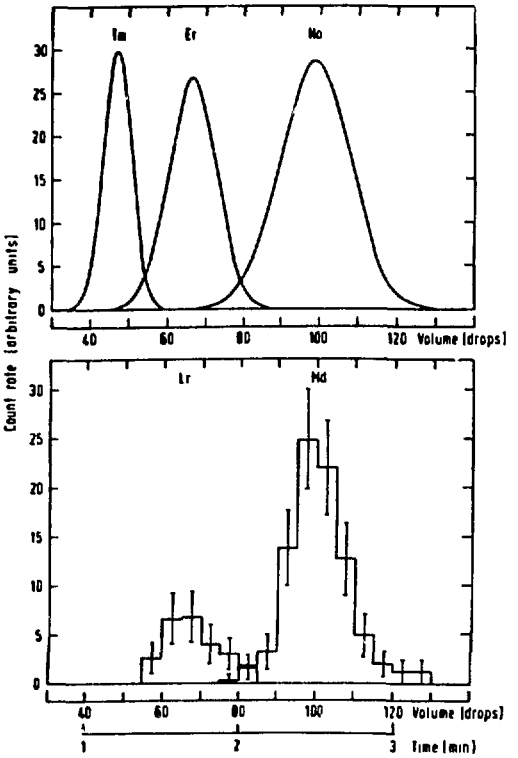

Tm
Er
Ho
Lr
Md
Count rate (arbitrary units)
Volume (drops)
Time (min)
0
5
10
15
20
25
30
40
60
80
100
120
1
2
3

Fig. 2

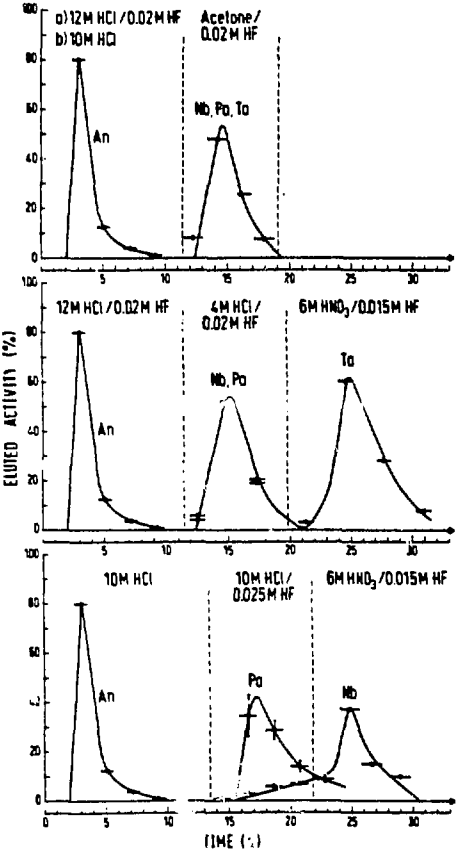

a) 12M HCl / 0.02M HF
b) 10M HCl
Acetone / 0.02M HF
An
Nb, Pa, Ta
12M HCl / 0.02M HF
4M HCl / 0.02M HF
6M HNO3 / 0.015M HF
An
Nb, Pa
Ta
10M HCl
10M HCl / 0.025M HF
6M HNO3 / 0.015M HF
An
Pa
Nb
ELUTED ACTIVITY (%)
TIME (')

Fig. 3

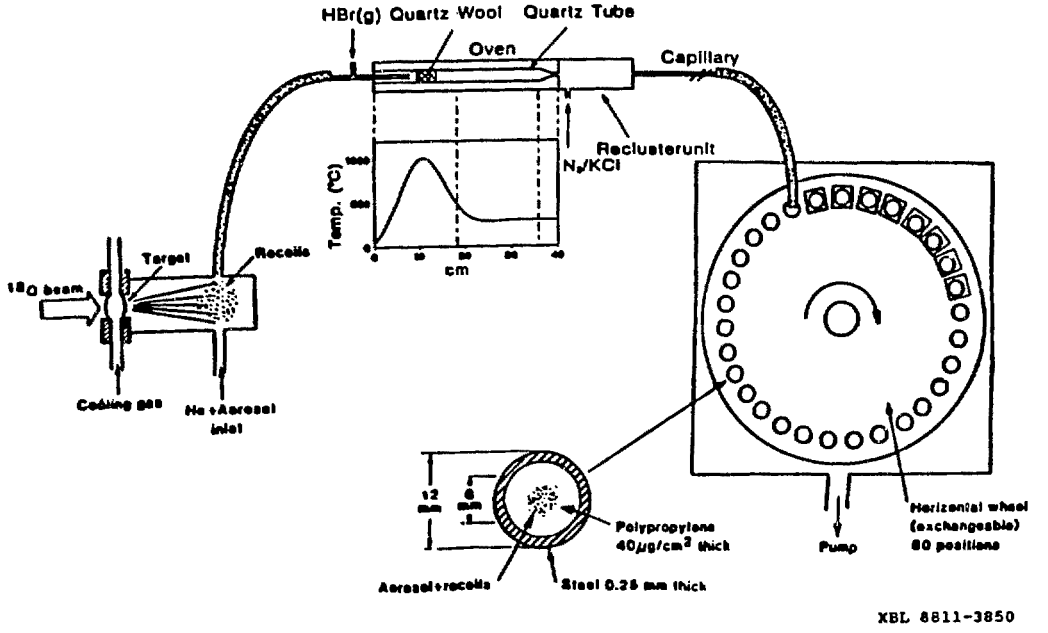

HBr(g)
Quartz Wool
Quartz Tube
Oven
Capillary
Recluster unit
$N_2$/KCl
Temp. (°C)
cm
Target
Recoils
$^{18}O$ beam
Cooling gas
He + Aerosol inlet
12 mm
6 mm
Polypropylene
40 μg/cm² thick
Aerosol+recoils
Steel 0.25 mm thick
Pump
Horizontal wheel
(exchangeable)
80 positions
XBL 8811-3850

Fig. 4