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RADIOCHEMICAL SEPARATION BY RETENTION ON IONIC PRECIPITATES

ADSORPTION TESTS ON 17 MATERIALS

by

F. GIRARDI, R. PIETRA and E. SABBIONI

1969

Joint Nuclear Research Center
Ispra Establishment - Italy

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ABSTRACT

The retention of different radio-ions on columns of seventeen ionic precipitates from different acid media was studied, in view of possible applications for radiochemical separations. The results of about 3,000 adsorption experiments, carried out in a standardized way, are presented schematically in periodic tables.

Twenty-one radiochemical separations, mainly in connection with activation analysis problems, were done to test the practical behaviour of potentially useful materials, and these are briefly described.

KEYWORDS

SEPARATION PROCESSES
IONS
EXTRACTION COLUMNS
PRECIPITATION
ACIDS
ADSORPTION
ACTIVATION ANALYSIS

INDEX

1. INTRODUCTION (*)

Inorganic ion exchangers have been applied for a long time in the nuclear energy field particularly when their outstanding resistance to high temperatures and high radiation doses make them preferable to organic ion exchangers (separation of fission products from spent fuel elements, deionization of reactor cooling water at high temperature). Many materials have been developped for such uses (1,2).

They have seldom been used for radiochemical separations applied to neutron activation analysis, despite the fact that a high selectivity for a few ions was often demonstrated.

In a few preceeding works (3,4,5,6) we showed that the retention behaviour of many inorganic materials, not usually employed as ion exchangers ,was interesting enough for many practical applications in destructive activation analysis.

Indeed,inorganic materials, not especially prepared as ion exchangers, can react with a solution containing trace ions with a number of possible reaction mechanisms, such as isotopic exchange, redox reactions, precipitation, formation of mixed crystals by recrystalization, and, of course, ion exchange. All these mechanisms can contribute to a different extent to the retention of different ions on a column of that material in an adsorption-elution experiment.

(*) Manuscript received on 14 May 1969.

Often, to clarify the actual retention mechanisms and describe them with comprehensive chemical laws can indeed be difficult; and the possibility of extrapolating the behaviour of ionic precipitates to different experimental conditions can be greatly hindered by the intervention of different reaction mechanisms in different media.

This does not prevent, however, the analyst from taking advantage of the unusual retention properties of many ionic precipitates, used in proper media, if he keeps the experimental conditions as close to the original ones as possible.

When a wanted chemical separation is still feasible under standardized working conditions, (the large variety of ionic precipitates which can be applied compensate for a more restricted choice of experimental conditions), then the limitation turns out to be an advantage, as the materials and columns can be prepared in advance and kept in stock and the execution can be left to less specialized personnel. The construction of automated machines can also be greatly simplified.

In this work about 3.000 adsorption-elution cycles were carried out in a standardized way over different ionic precipitates from various media for a preliminary screening of possible useful materials for radiochemical separations applied to activation analysis.

The results were reported schematically in a series of periodic tables. Possible analytical applications can be inferred from the behaviour of different ions in each couple column/medium, and work is being carried out to simplify this task. The experiments were carried out with radioactive tracers which were obtained by neutron activation in a nuclear reactor, with irradiation times ranging from minutes to three weeks, depending on the half-life of the radionuclide. The amount of tracer used was that required to obtain a reasonable counting rate on a gamma spectrometer, by counting the whole of the column or elution volumes. In this way the actual carrier concentration varies greatly from one radiotracer to another depending mainly on its activation cross section. While this is certainly a drawback for understanding the reaction mechanisms, in the practical analytical use it can be considered an advantage, as a relatively close simulation of a destructive activation analysis is thus obtained.

The application of the reported results to actual separation cases is, of course, not entirely straightforward.

The retention capacity of inorganic ion exchangers or ionic precipitates, in general, are usually lower than those of the organic exchangers, and moreover they vary considerably from ion to ion. For example, the retention capacity of hydrated antimony pentoxide for the alkaline ions in 0.1 M HNO_3 (in milliequivalents per gram) has the following values: Na^+ : 2.61, K^+ : 1.7, Rb^+ : 1.45, Cs^+ : 0.15, (7).

As a consequence, ions for which the material has a low retention capacity can exhibit a different behaviour for different ion concentrations. Also ions present in extremely low concentrations can frequently show unusual retention or long elution "tails". The addition of 50-100 μg of carrier when elution is wanted is a recommended practice to avoid both difficulties.

Elements present in large concentrations (matrix elements) can also alter the behaviour of the exchanger, as it happens with organic exchangers.

Even with these limitations, we found that the behaviour indicated in the tables is very often exactly respected in many practical applications for activation analysis, where ion concentrations are often rather small. Together with the results of the retention experiments we briefly report the results of practical applications, when done.

This report is far from an exhaustive study of analytical applications of ionic precipitates, and indeed it is more an introduction to that study than a real scientific work. However, the possibility of applying directly the data as they are presented here to the development of separation schemes, and the interest at recent congresses arose from their use has convinced us that the presentation of these results was worth while.

The data presented here are not correlate with each other enough to make the detection of possible mistakes easy. The number of data is also high enough to make it possible and even probable the occurrence of such mistakes, even if most of the experiments were repeated at least twice. We shall be grateful to those, who will inform us of such errors.

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2. EXPERIMENTAL PROCEDURES

The ionic precipitates used in the present work were mostly of commercial origin and the name of the manufacturer and references on the preparation process, when available, are given for each individual material in the next paragraph. In table I the list and addresses of the manufacturers are given.

Most of the materials used in this work were previously known to exhibit ion exchange properties, or they had been briefly studied by us for some special purposes. Others were added on which no information on their possible application was available to us, but could be easily packed into columns with good flow-rate characteristics, and insoluble or only slightly soluble in the proposed medium. Other insoluble materials (SeS_2, Sb_2O_3, MoO_3, TiO_2, $BaSO_4$, Cr_2O_3, PbO_2, NiF_4, CuO, V_2O_5, $CoWO_4$, Cu_2O, Co_3O_4) were discarded after a few preliminary assays, as the particle size of the material available to us was too fine for the preparation of columns with good flow-rate behaviour.

Dowex 1 and Dowex 50 were also tested, both in view of their possible use together with inorganic exchangers, and to be used as controls of anion and cation exchange in the study of the reaction mechanisms.

The materials tested were used as received, occasionaly after sieving to eliminate finer particles to improve the elution flow-rate. Preliminary treatments only entailed washing the column with 5 ml of the eluting agent immediately before the adsorption step.

The radioactive tracers (except ^{22}Na and ^{54}Mn, which were of commercial origin), were prepared by neutron activation of the stable elements, in form of solid salts, in the Ispra 1 reactor. The irradiation times ranged from a few minutes to several weeks, depending on the activation cross section and the half-life of the radionuclide formed. The irradiated salts were then dissolved and stored, generally as a 1 M HCl solution.

The solutions for the adsorption step were prepared by taking aliquots from the mother solution (generally 10-100 λ) and diluting them to 30-50 ml with the required acid. From this second stock 5 ml fractions were taken for each tracer experiment.

The tracer used, and the approximate final carrier concentrations, are reported in table II.

The tracer experiments were carried out in the following way: disposable polyethilene columns, prepared by VEMOR (Monvalle, Varese, Italy) (figure 1) were used (internal diameter 7 mm). They include a 15 ml reservoir, and they can be easily stacked one on top of the other when a series of column is needed.

The columns were prepared by putting a quartz wool plug (or a teflon wool plug for the tracer experiments in HF) at the bottom and filling the column with the exchanger up to a 3 cm level.

A preliminary wash with 5 ml of the eluting solution was done before the adsorption step, to wet and settle the column bed. The adsorption step (5 ml) was then carried out, and then two successive 15 ml fractions were passed through. The eluted solutions were collected into two 20 ml polyethilene bottles, the first collecting the adsorption and first 15 ml fraction, the second collecting the successive 15 ml fraction. The second fraction was diluted to 20 ml and both bottles were then analyzed by gamma ray spectroscopy.

The column bed was transferred into a third bottle and analyzed in the same way. An experimental correction factor was used to relate the counting rate of the column to the counting rate of the eluted solutions.

Most of the countings of the tracer experiments were done with a 3" x 3" NaI(Tl) scintillator coupled to a 200 channel LABEN analyzer. In tracer experiment with pure β emitters (^{32}P, ^{35}S, ^{90}Y, ^{233}Th), counting was done with a Geiger counter. The sources were prepared by taking 1 ml of solution and drying it under an infrared lamp.

To count the columns, they were dissolved when possible and treated as the eluted solutions, otherwise they were carefully dried and stirred, and a weighed part was spread over the counting tray. The 1 ml aliquot from the eluted solution was then added to an identical weight of fresh exchanger, which was then stirred, dried and spread over a counting tray in the same way as described above.

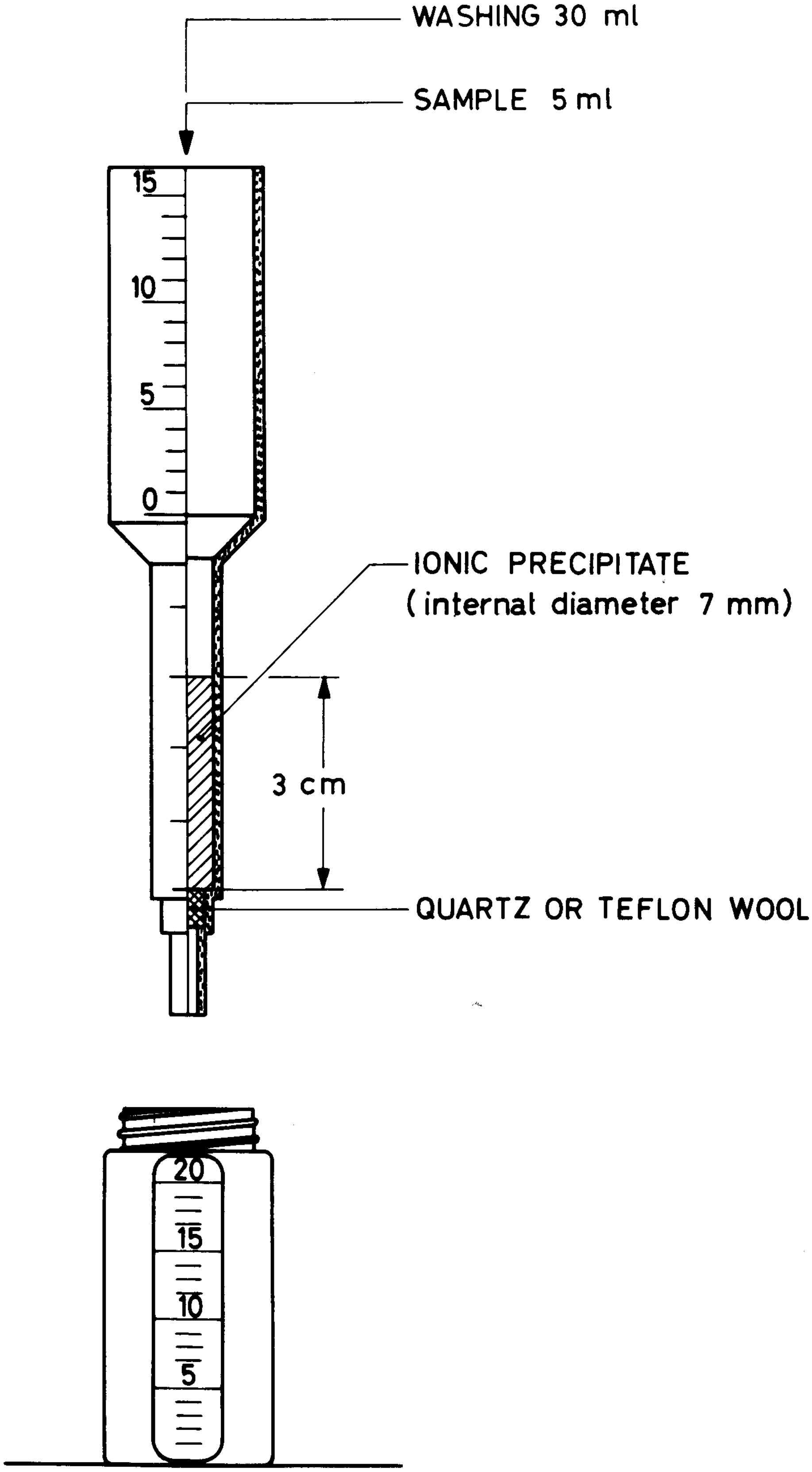
WASHING 30 ml
SAMPLE 5 ml
15
10
5
0
IONIC PRECIPITATE
(internal diameter 7 mm)
3 cm
QUARTZ OR TEFLON WOOL
20
15
10
5

Figure 1

3. RESULTS

The results of the tracer experiments for each ionic precipitate in various media are reported in the following paragraphs, in form of periodic tables. The following codes were used:

○ : element eluted (over 97%)

● : element retained (over 99%)

◐ : element partially retained (the black area is proportional to the amount retained)

⊘ : behaviour not well reproducible

no disk: the element was not tested.

The tables are numbered successively, and the code words of the material and of the medium are indicated in brackets. (see table III for the keys of the code).

Each paragraph is completed by a summarized description of applications made.

Only the part referring to the separation conditions and the results obtained, is given. Details on the irradiation and counting conditions and on the destructive producers used, were generally omitted to avoid repetition of non-essential data.

Reference to published work on the material tested or on materials of similar chemical composition are given for each paragraph.

3.1 Hydrated Manganese Dioxide (HMD)

3.1.1 Material

Commercial HMD ("RA-2", Carlo Erba, Italy), prepared according to reference (19) was used.

3.1.2 Tracer experiments

Carried out in the following media:

a) 0.1 M HNO_3 at 65°C (61 ions): table 1 (HMD/0.1N 65°C)
b) 1 M HNO_3 (50 ions): table 2 (HMD/1N)
c) 1 M $HClO_4$ (51 ions): table 3 (HMD/1P)
d) 6 M HF (52 ions): table 4 (HMD/6F)
e) 14 M HNO_3 (51 ions): table 5 (HMD/14N)

3.1.3 Applications

HMD was applied to various radiochemical separations, such as removal of Fe and Cr for the determination of Zn and Co in a Fe-Cr alloy, activation analysis of mussel shells (removal of ^{47}Ca), and of leaf tissues (separation of Na from Mn and K) (19).

A Tc^{99m} generator based on the use of a HMD column, (20) and the application of HAP, HMD and TDO to the determination of chromium in blood were recently reported (21).

Other applications were:

a) Determination of Cu in steel (total removal of ^{187}W and partial removal of ^{56}Mn from 1 M $HClO_4$, determination of ^{64}Cu in the eluate, figure 2)

b) Determination of Na, K, Mn, Zn, Cs, Ba, Mg, Sr in a fish muscle (see paragraph 3.8.3)

c) Preparation of carrier free Co^{58} from neutron irradiated nickel by the reaction $^{58}Ni(n,p)$ ^{58}Co. Irradiated nickel in a 6 M HF solution was passed over HMD. ^{58}Co is retained, and it can be eluted with 14M HNO_3. The concentration of Ni^{++} in the solution must be lower than 1 mg/ml, or losses in the retention of ^{58}Co are found.

3.1.4 HMD references

(references 8 to 18 refer to other types of manganese dioxide used as inorganic exchanger, references 19 to 22 refer to HMD in particular).

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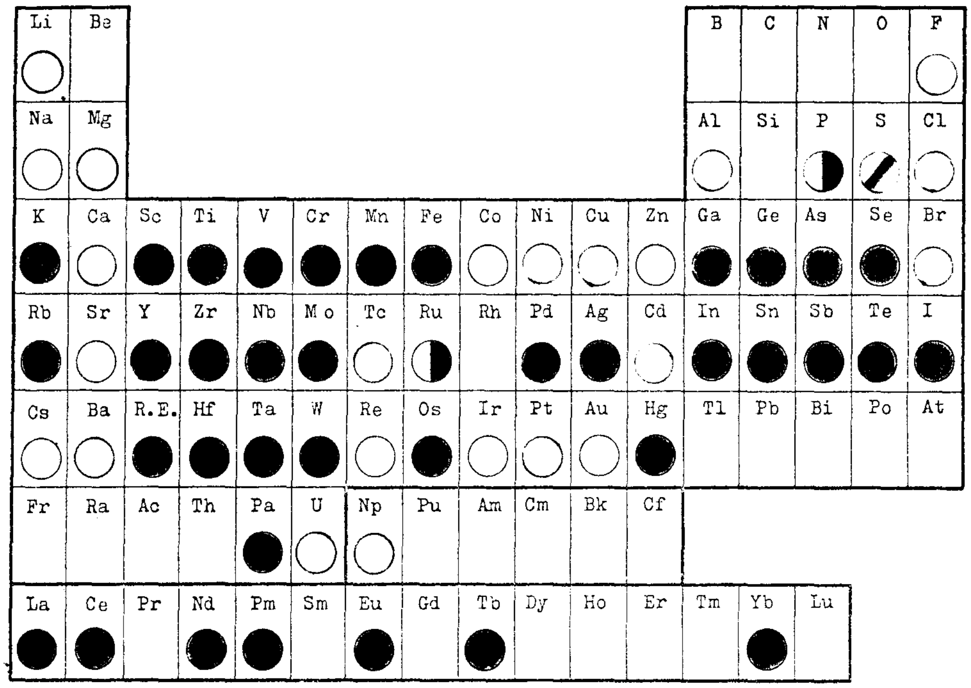
HYDRATED MANGANESE DIOXIDE

1(HMD/0.1N 65°C)

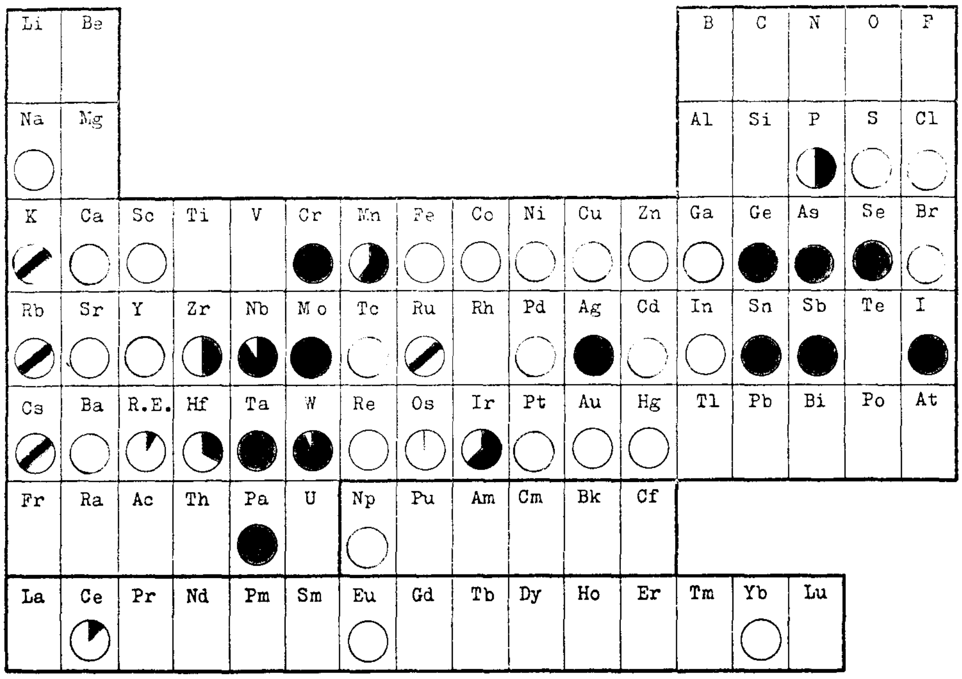
0.1 M HNO_3 at 65°C



HYDRATED MANGANESE DIOXIDE

2(HMD/1N)

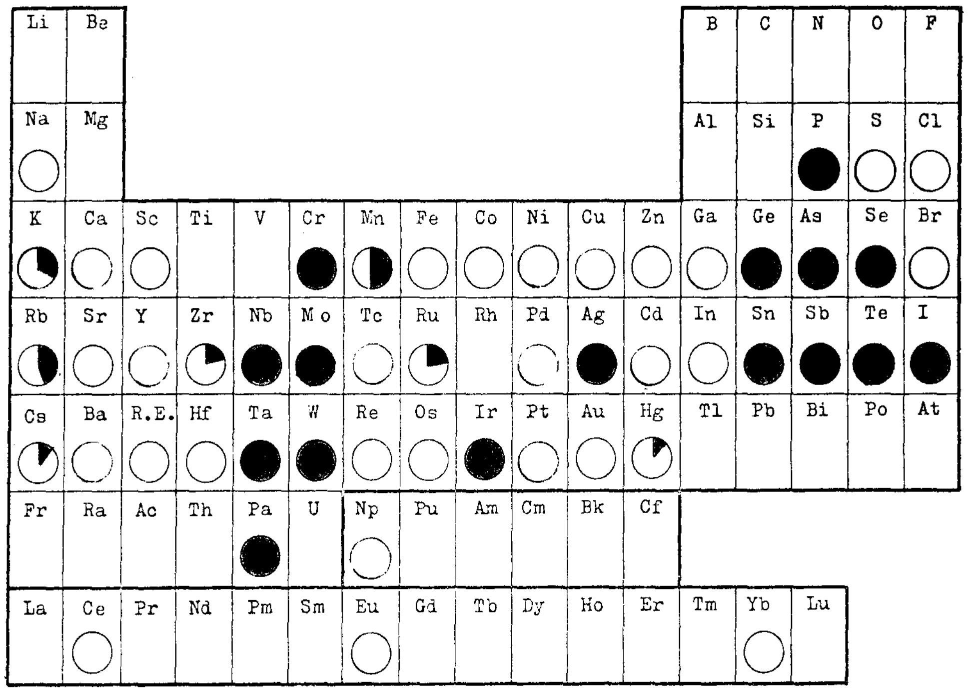
1 M HNO_3



HYDRATED MANGANESE DIOXIDE

3(HMD/1P)

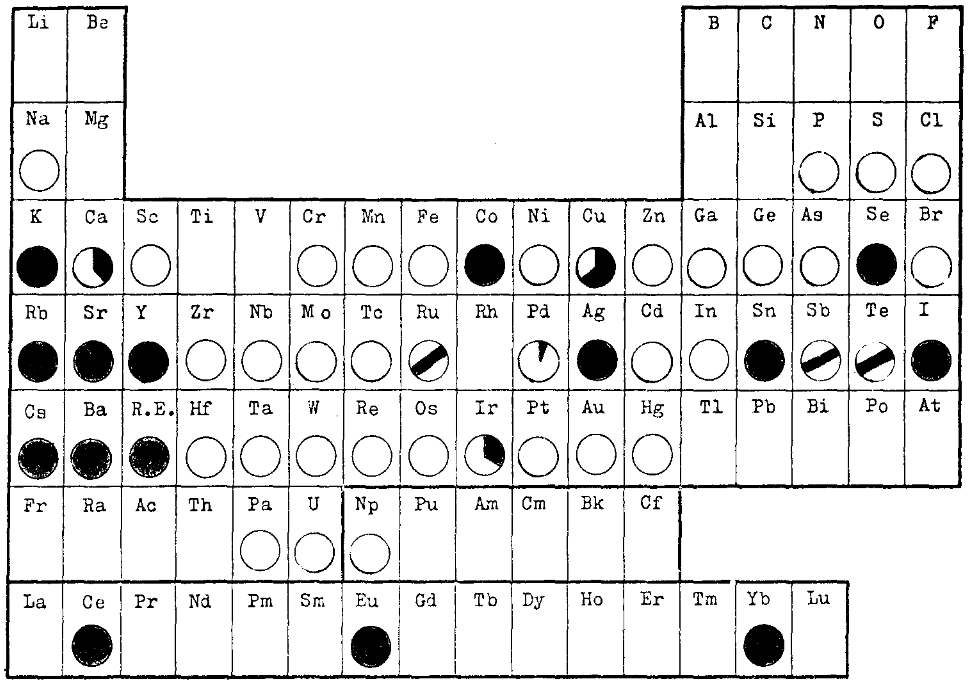
1 M $HClO_4$



HYDRATED MANGANESE DIOXIDE

4(HMD/6F)

6 M HF

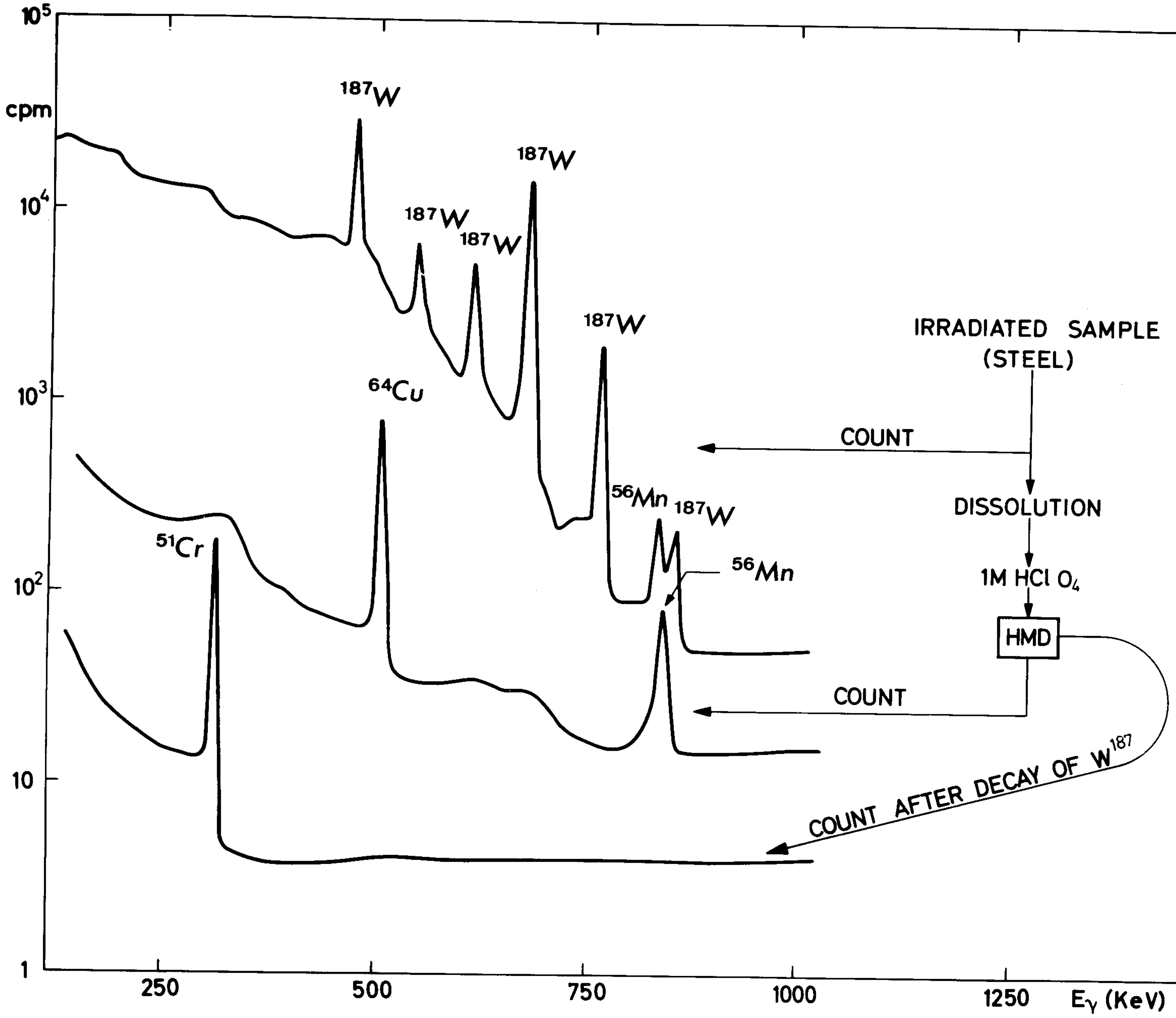


HYDRATED MANGANESE DIOXIDE

14 M HNO_3

5(HMD/14N)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ◕	S ○	Cl ○
K ○	Ca ○	Sc ○	Ti	V	Cr ●	Mn ◕	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ●	As ●	Se ●	Br ○
Rb ◔	Sr ◔	Y ○	Zr ○	Nb ●	Mo ●	Tc ○	Ru ○	Rh	Pd ○	Ag ●	Cd ○	In ○	Sn ●	Sb ●	Te ●	I ●
Cs ◔	Ba ○	R.E. ○	Hf ○	Ta ●	W ●	Re ◔	Os ○	Ir ◑	Pt ○	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		



cpm
10^5
10^4
10^3
10^2
10
1
250
500
750
1000
1250
Eγ (KeV)
187W
187W
187W
187W
187W
187W
64Cu
56Mn
56Mn
51Cr
IRRADIATED SAMPLE (STEEL)
COUNT
DISSOLUTION
1M HCl O4
HMD
COUNT
COUNT AFTER DECAY OF W187

Figure 2

3.2 Anhydrous Manganese Dioxide (AMD)

3.2.1 Material

AMD was prepared by courtesy of the firm Carlo Erba, Italy. The X-ray powder diffraction pattern corresponded to a pirolusite structure.

3.2.2 Tracer experiments

Carried out in the following media:

a) 1 M $HClO_4$ (50 ions): table 6 AMD/1P

b) 6 M HF (50 ions): table 7 AMD/6F

c) 14 M HNO_3 (51 ions): table 8 AMD/14N

3.2.3 Applications

a) Determination of Ag in mollusks (Octopus): ^{110m}Ag was fixed on AMD from 6M HF. Fe,Co and Zn were removed (figure 3).

b) Determination of Co and Cs in soil samples. The irradiated soil sample showed a complex γ -spectra in which ^{46}Sc and the rare earths radioisotopes were prevailing.
The irradiated sample (30 mg) in 5 cc of 6M HF solution was passed on a column of AMD coupled to one with cerous oxalate. The first retained the rare earths, the second retained ^{46}Sc. ^{60}Co and ^{134}Cs were measured in the eluate.

ANHYDROUS MANGANESE DIOXIDE

1 M $HClO_4$

6(AMD/1P)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ○	S	Cl ○
K ○	Ca ○	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ◔	As ●	Se ○	Br ○
Rb ○	Sr ○	Y ○	Zr ○	Nb ◔	Mo ●	Tc ○	Ru ●	Rh	Pd ○	Ag ●	Cd ○	In ○	Sn ●	Sb ●	Te ●	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ○	Re ◔	Os ◔	Ir ●	Pt ○	Au ●	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

ANHYDROUS MANGANESE DIOXIDE

6 M HF

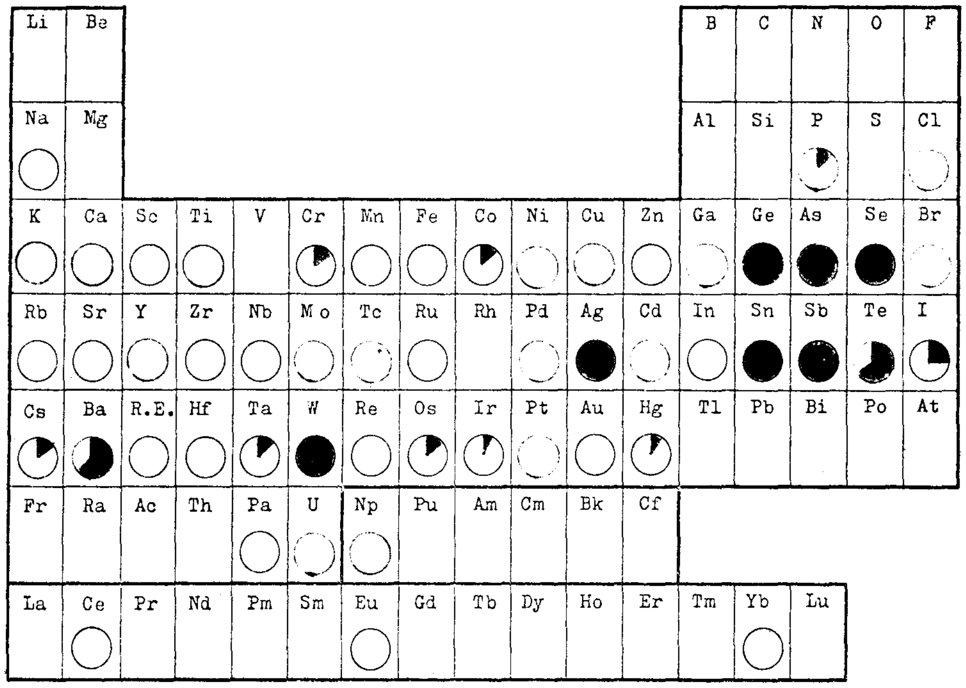
7(AMD/6F)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ○	S	Cl ○
K ○	Ca ○	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ○	As ◔	Se ●	Br ○
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo ○	Tc ○	Ru ◑	Rh	Pd ○	Ag ●	Cd ○	In ○	Sn ○	Sb ○	Te ◔	I ○
Cs ○	Ba ○	R.E. ●	Hf ○	Ta ○	W ○	Re ○	Os ○	Ir ◔	Pt ○	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np ◔	Pu	Am	Cm	Bk	Cf					
La	Ce ●	Pr	Nd	Pm	Sm	Eu ●	Gd	Tb	Dy	Ho	Er	Tm	Yb ●	Lu		

ANHYDROUS MANGANESE DIOXIDE

8(AMD/14 N)

14 M HNO_3



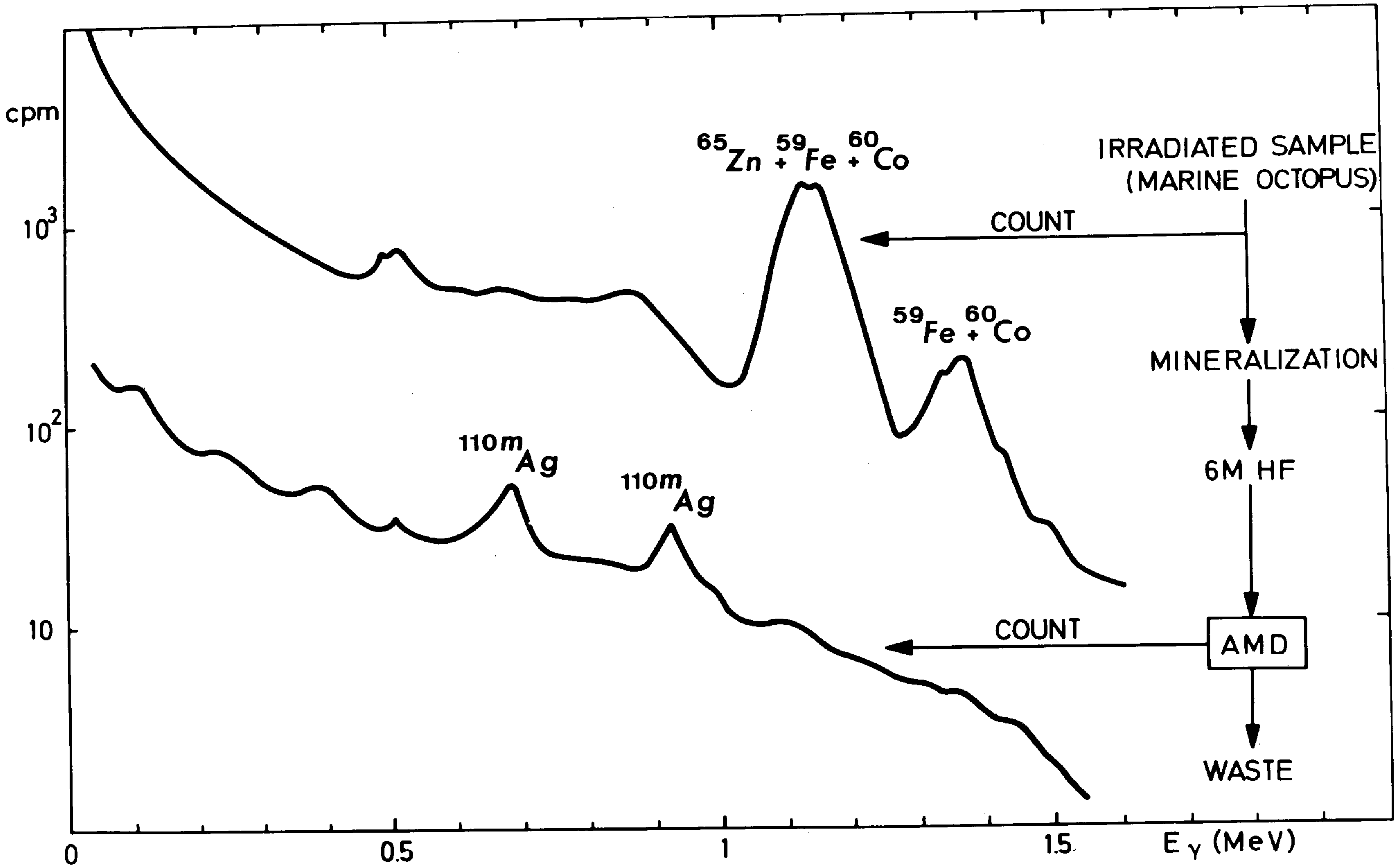

cpm
10^3
10^2
10
0
0.5
1
1.5
E_γ (MeV)
$^{65}Zn + ^{59}Fe + ^{60}Co$
$^{59}Fe + ^{60}Co$
^{110m}Ag
^{110m}Ag
IRRADIATED SAMPLE
(MARINE OCTOPUS)
COUNT
MINERALIZATION
6M HF
AMD
COUNT
WASTE

Figure 3

3.3 Silicon Dioxide (SDO)

3.3.1 Material

Commercial Silicon dioxide ("R.P." Reagent grade, Carlo Erba, Italy) was used.

3.3.2 Tracer experiments.

Carried out in the following media:

a) 1M $HClO_4$ (49 ions): table 9 (SDO/1P)

b) 7M HNO_3 (49 ions): table10 (SDO/7N)

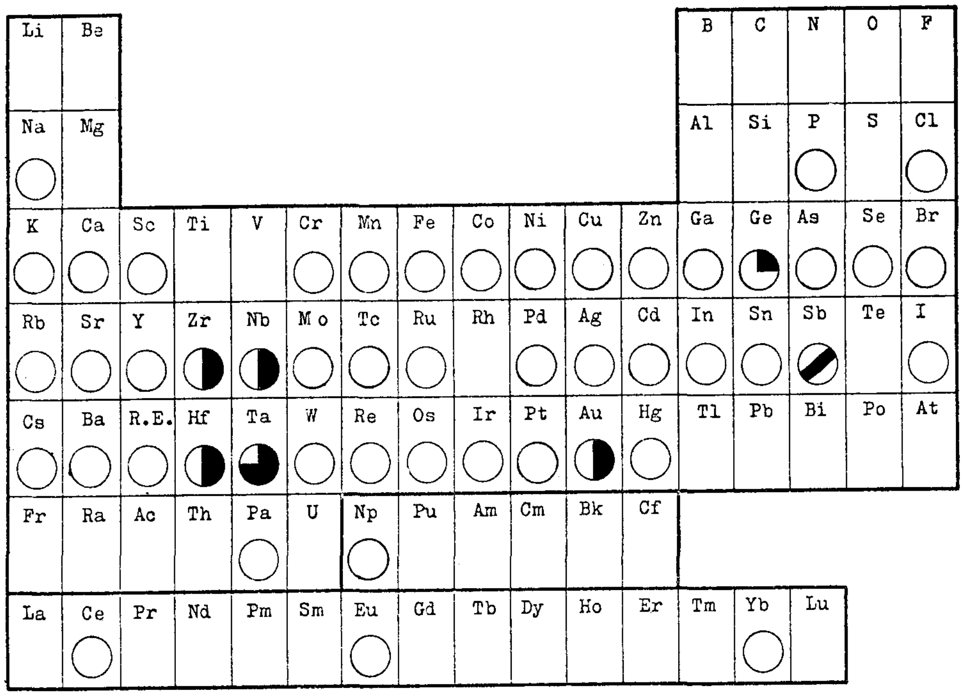
3.3.3 Applications

SDO does not seem to have a practical interest, at least in the two media of the tracer experiments.

SILICON DIOXIDE

1M $HClO_4$

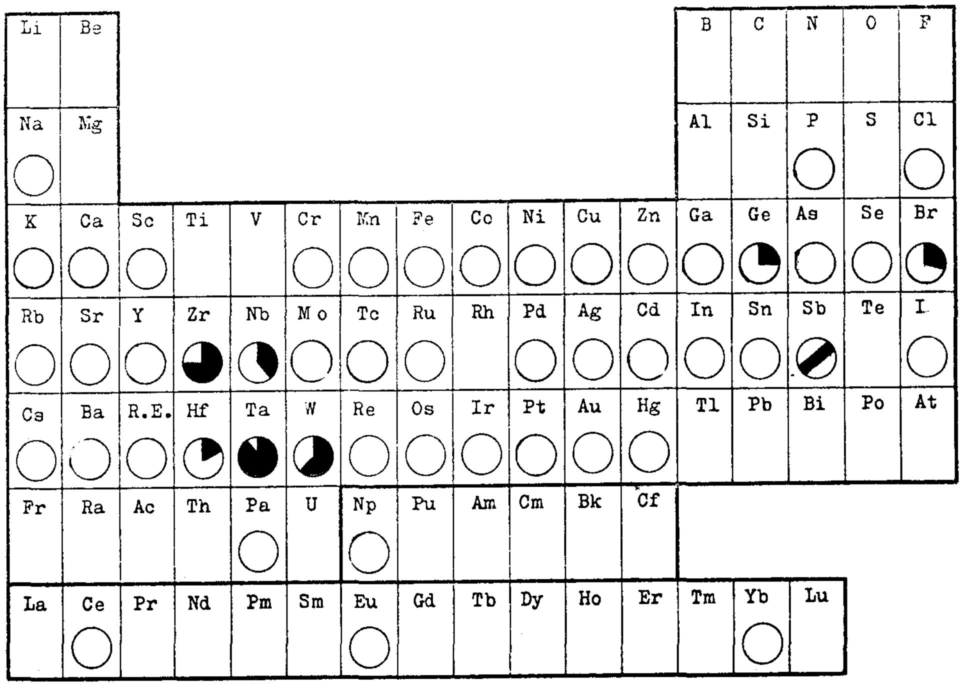
9(SDO/1P)



SILICON DIOXIDE

7M HNO_3

10(SDO/7N)



3.4 Hydrated Antimony Pentoxide (HAP)

3.4.1 Material

Commercial HAP (RA-1, "Carlo-Erba, Italy) prepared according to reference (23), was used.

3.4.2 Tracer experiments

Carried out in the following media:

a) 1 M HNO_3 (36 ions): table 11 (HAP/1N)
b) 1 M $HClO_4$(51 ions): table 12 (HAP/1P)
c) 6 M HCl (58 ions): table 13 (HAP/6Cl)
d) 6 M $HClO_4$(36 ions): table 14 (HAP/6P)
e) 6 M HF (53 ions): table 15 (HAP/6F)
f) 7 M HNO_3 (32 ions): table 16 (HAP/7N)
g)12 M HCl (60 ions): table 17 (HAP/12Cl)
h)14 M HNO_3 (53 ions): table 18 (HAP/14N)

3.4.3 Applications

Various applications to the selective removal of radiosodium from neutron activated specimens were already reported (22, 23, 24, 25).

Other applications, involving the separation of other radionuclides, were:

a) Determination of Co, Rb, Sr, Sc, Zn, Fe, in mollusks. The irradiated sample in 1M HNO_3 with mg amounts of carriers added for each element was passed on HAP. Cs, Rb, Sr and Sc are retained. See figure 4.

b) Determination of Ta in Zr: based on the adsorption of Ta from 12 M HCl on HAP. Carrier-free Nb^{95} from decay of Zr^{95} was mostly retained on HAP. The addition of 5 mg Nb carrier during the dissolution of the sample decreases the amount retained by a factor 10^2. See figure 5.

c) Determination of K, Cs, Sr and Cu in human lung tissues: the irradiated sample is dissolved in fuming HNO_3 and directly passed on a HAP column. The eluate is diluted to 1 M and passed on another HAP column (K, Cs, Sr retained; Cu and Mn eluted, see figure 6).

d) Determination of Cu and Zn in leaf tissues (see paragraph 3.17.3).

e) Determination of Na, K, Mn, Zn, Cs, Ba, Mg, Sr in fish muscle (see paragraph 3.8.3).

f) Preparation of carrier-free ^{95}Nb from decay of ^{95}Zr. Neutron activated zirconium (100 mg) is dissolved and put in 20 cc of 14 M HNO_3 and passed on HAP. The retained Nb is eluted with 6M HF.

g) A Tc^{99m} isotope generator was formed by adsorbing irradiated Mo (15 mg) on HAP from 30 cc of 14 M HNO_3. Tc^{99m} was "milked" 10 times successively with 14 M HNO_3 and still no ^{99}Mo was detected in the eluate.

h) Preparation of carrier free Sc^{47} from the decay of Ca^{47}. Neutron activated $CaCO_3$ (1.25 g) was dissolved in 30 cc of 6 M $HClO_4$ and passed on a HAP column. ^{47}Sc is retained. Elution can be done with 6 M HF.

i) Determination of Mn and Cu in blood and mollusk shells: the irradiated material in 1 M $HClO_4$ was passed in HAP (Na and K removed). ^{64}Cu and ^{56}Mn are determined in the eluate.

l) Determination of Fe, Cr, Zn in mollusk shells: the irradiated shell in 6M $HClO_4$ was passed on HAP (^{46}Sc removed, ^{59}Fe, ^{51}Cr, ^{65}Zn in the eluate).

m) Determination of Fe, Cr, Zn in blood (see paragraph 3.8.3).

n) Determination of Cu and Mn in bone tissue (see paragraph 3.8.3).

3.4.4 References

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Journal of Radioanal.Chem. 1, 169 (1968).

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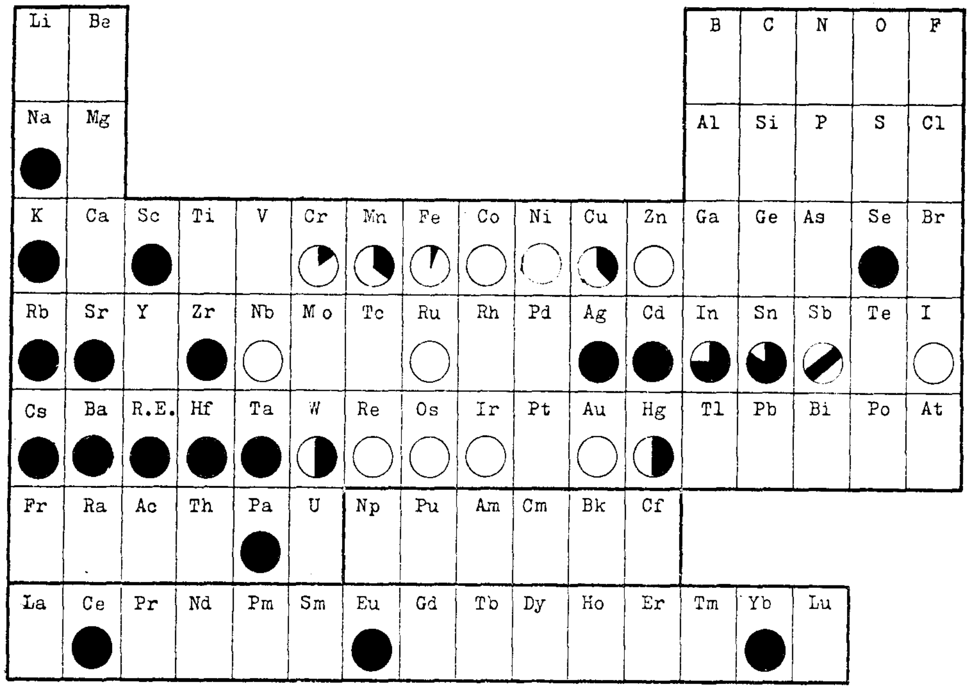
Internat.Conf.Modern Trends in Activation Analysis
1968, paper n° 59.

HYDRATED ANTIMONY PENTOXIDE

1 M HNO_3

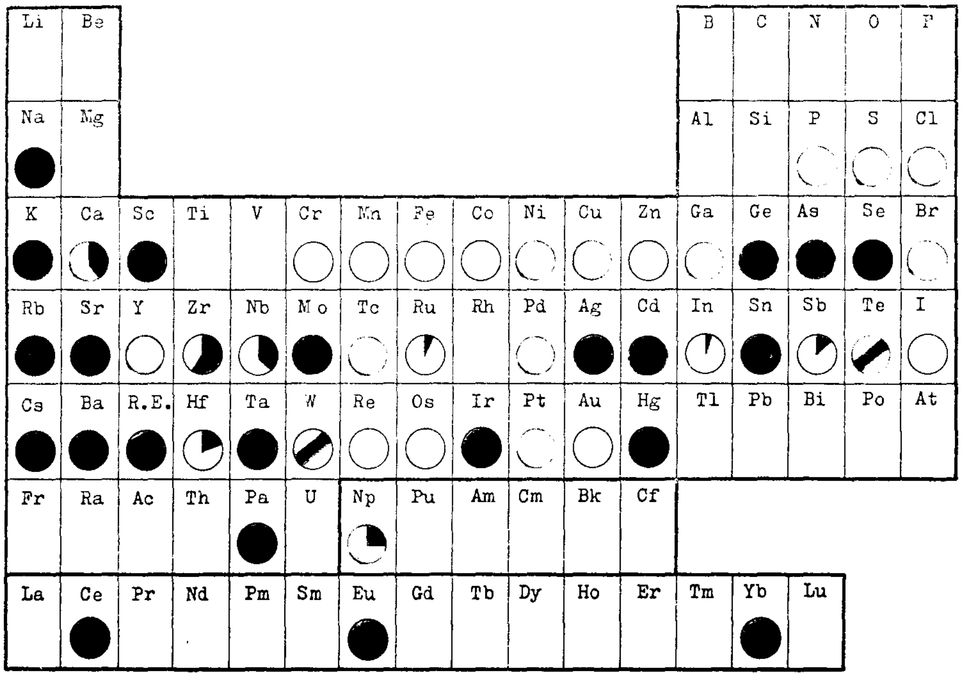
11(HAP/1N)



HYDRATED ANTIMONY PENTOXIDE

1 M $HClO_4$

12(HAP/1P)



HYDRATED ANTIMONY PENTOXIDE

6 M HCl

13(HAP/6Cl)

Li	Be											B	C	N	O	F ◔
Na ●	Mg											Al ○	Si	P ○	S ○	Cl ○
K ◔	Ca ○	Sc ○	Ti ○	V ○	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ○	As ○	Se ○	Br ○
Rb ◕	Sr ◔	Y ○	Zr ○	Nb ●	Mo ○	Tc ○	Ru ○	Rh	Pd ○	Ag ○	Cd ○	In ○	Sn ○	Sb ○	Te ○	I ○
Cs ◔	Ba ◔	R.E. ○	Hf ○	Ta ●	W ○	Re ○	Os ○	Ir ○	Pt ○	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra ◔	Ac	Th	Pa ◔	U ○	Np ○	Pu	Am	Cm	Bk	Cf					
La ○	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

HYDRATED ANTIMONY PENTOXIDE

6 M $HClO_4$

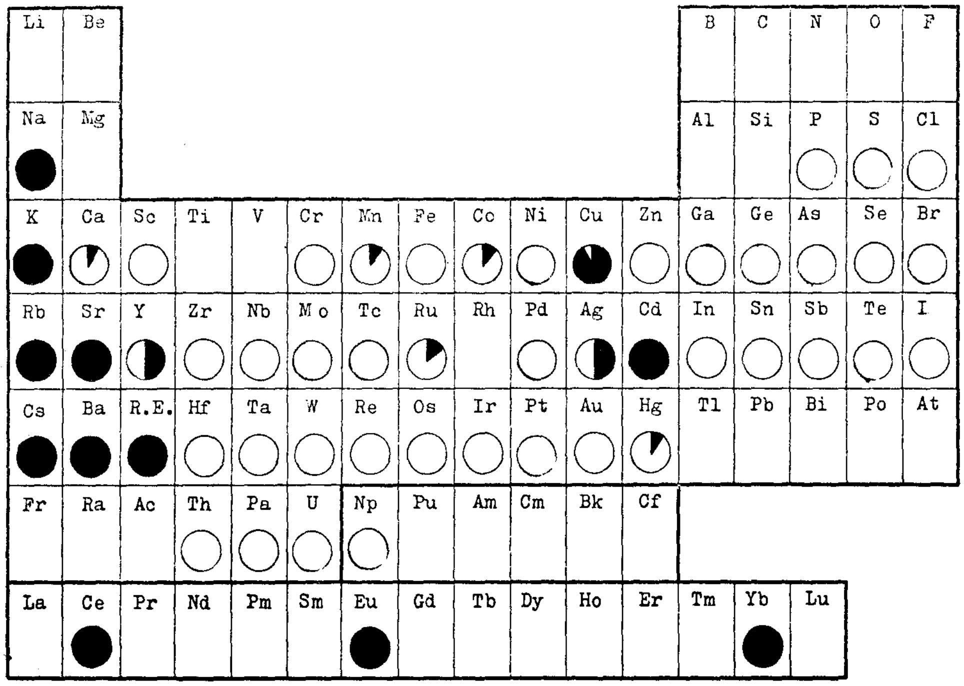
14(HAP/6P)

Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K ○	Ca	Sc ●	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ○	Y	Zr ◔	Nb ◔	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd ●	In ○	Sn ●	Sb ●	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

HYDRATED ANTIMONY PENTOXIDE

6 M HF

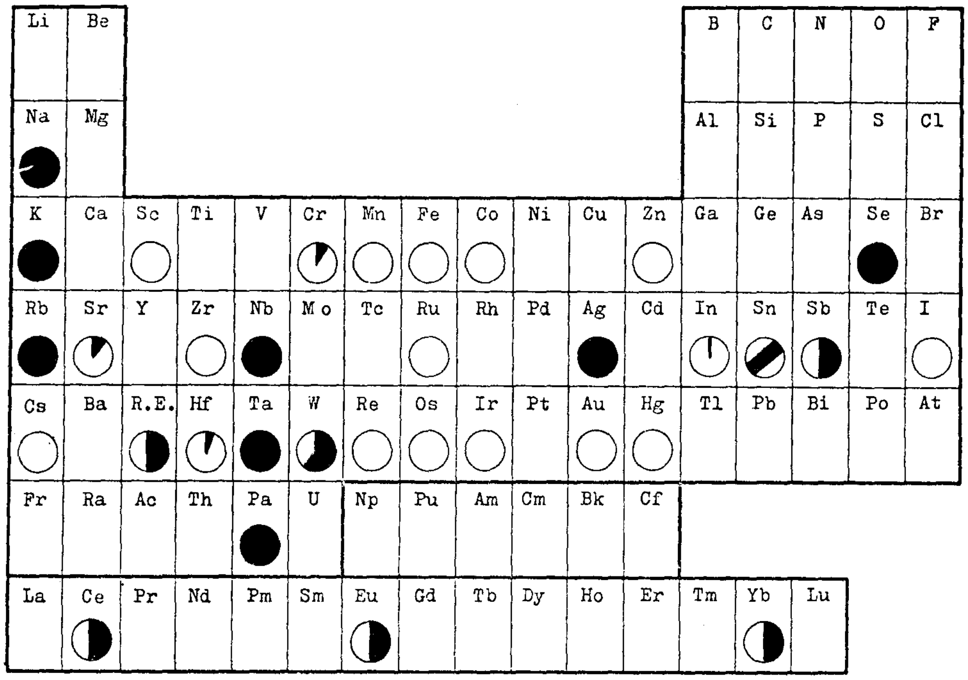
15(HAP/6F)



HYDRATED ANTIMONY PENTOXIDE

7 M HNO_3

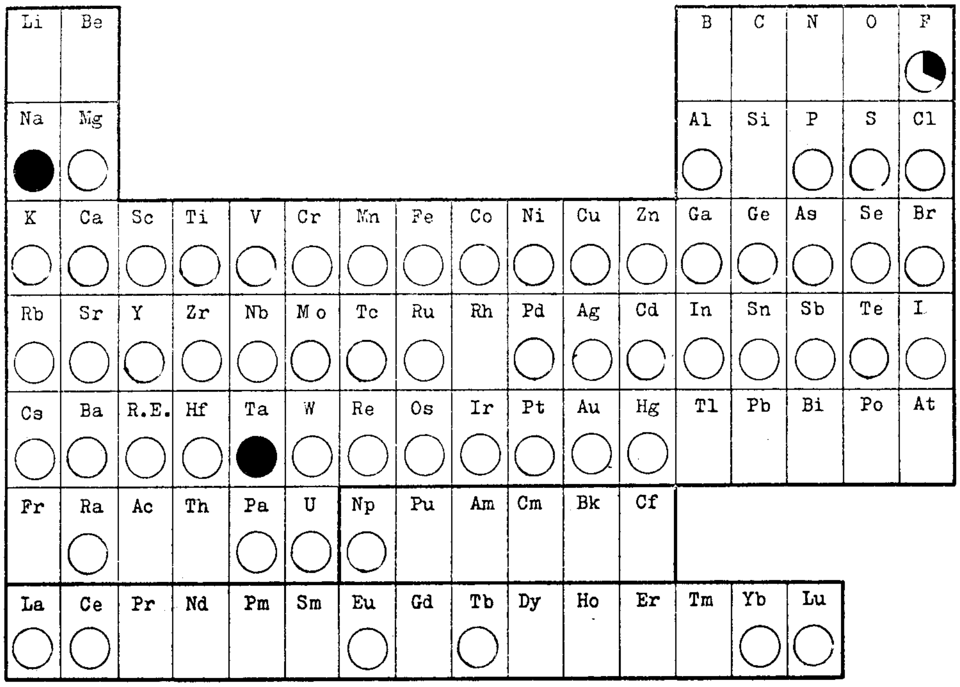
16(HAP/7N)



HYDRATED ANTIMONY PENTOXIDE

12 M HCl

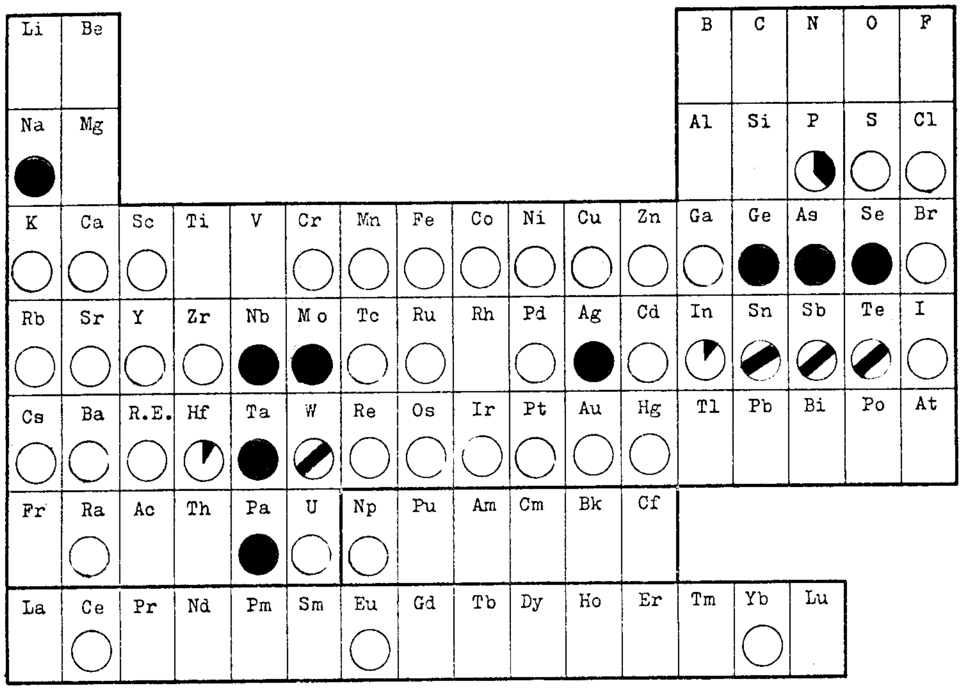
17(HAP/12Cl)



HYDRATED ANTIMONY PENTOXIDE

14 M HNO_3

18(HAP/14N)



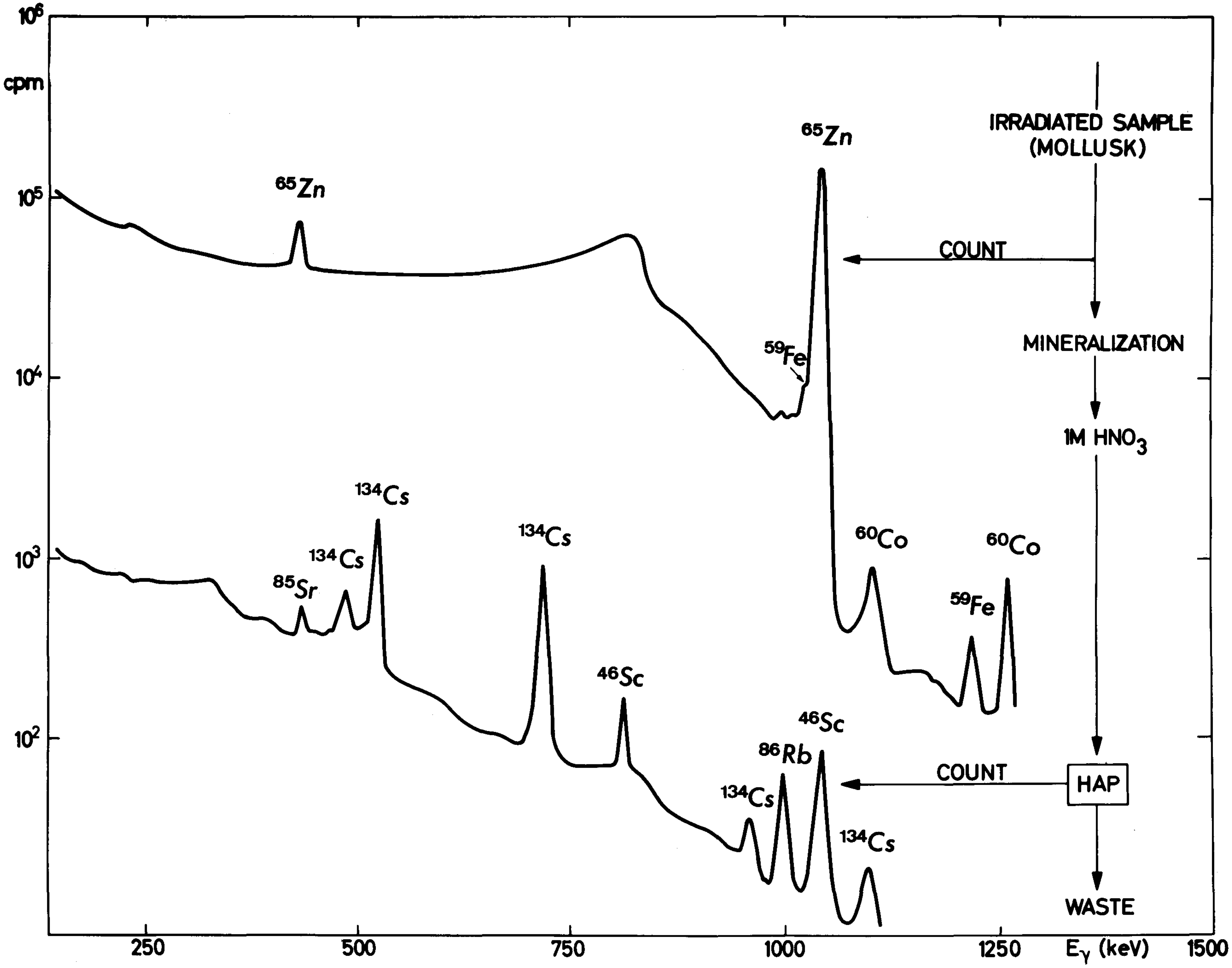

10^6
cpm
10^5
10^4
10^3
10^2
250
500
750
1000
1250
1500
E_γ (keV)
65Zn
65Zn
59Fe
60Co
59Fe
60Co
85Sr
134Cs
134Cs
134Cs
46Sc
134Cs
86Rb
46Sc
134Cs
IRRADIATED SAMPLE
(MOLLUSK)
COUNT
MINERALIZATION
1M HNO3
COUNT
HAP
WASTE

Figure 4

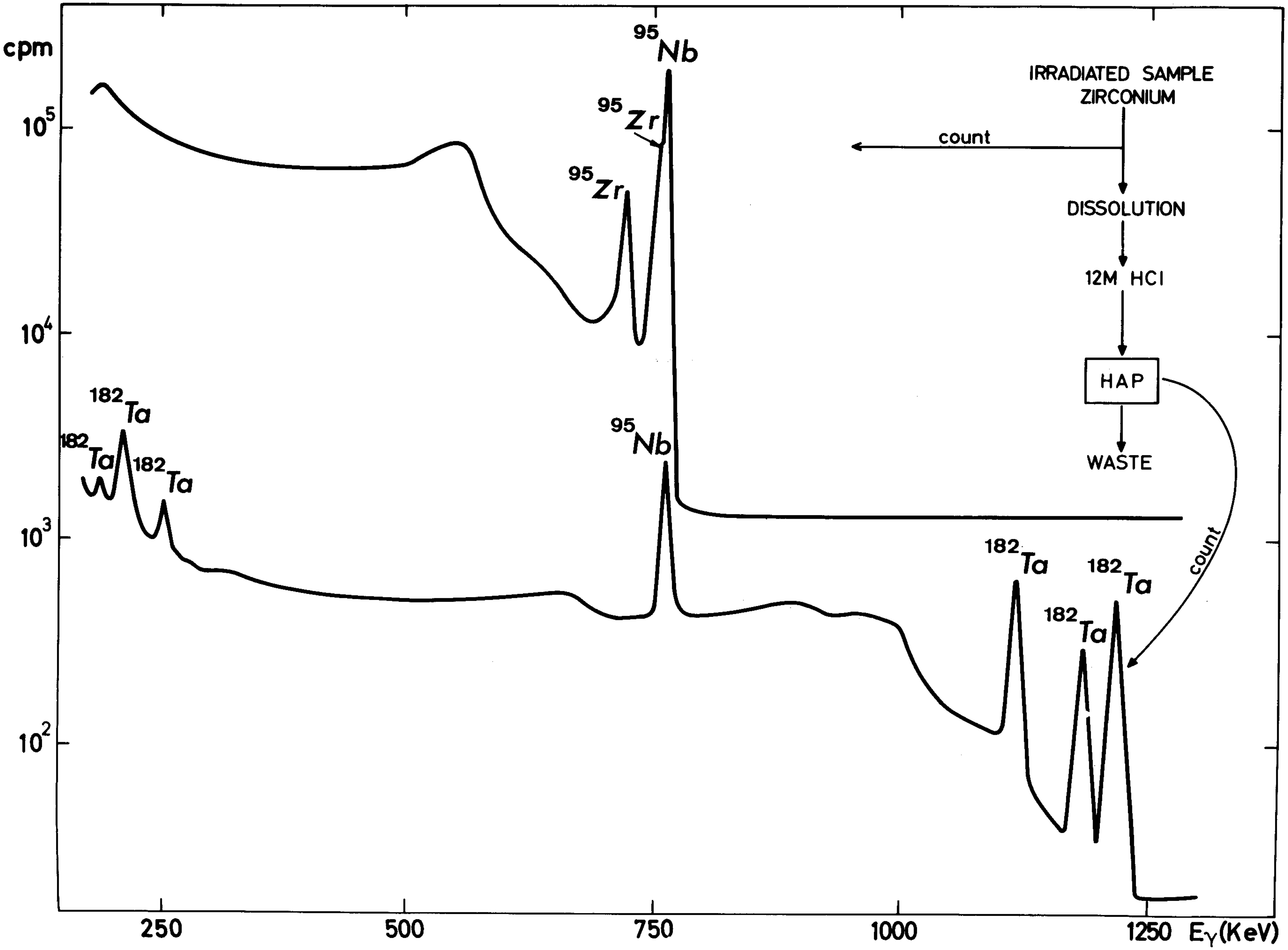

cpm
10^5
10^4
10^3
10^2
250
500
750
1000
1250
Eγ(KeV)
^{95}Nb
^{95}Zr
^{95}Zr
^{182}Ta
^{182}Ta
^{182}Ta
^{95}Nb
^{182}Ta
^{182}Ta
^{182}Ta
IRRADIATED SAMPLE
ZIRCONIUM
count
DISSOLUTION
12M HCl
HAP
WASTE
count

Figure 5

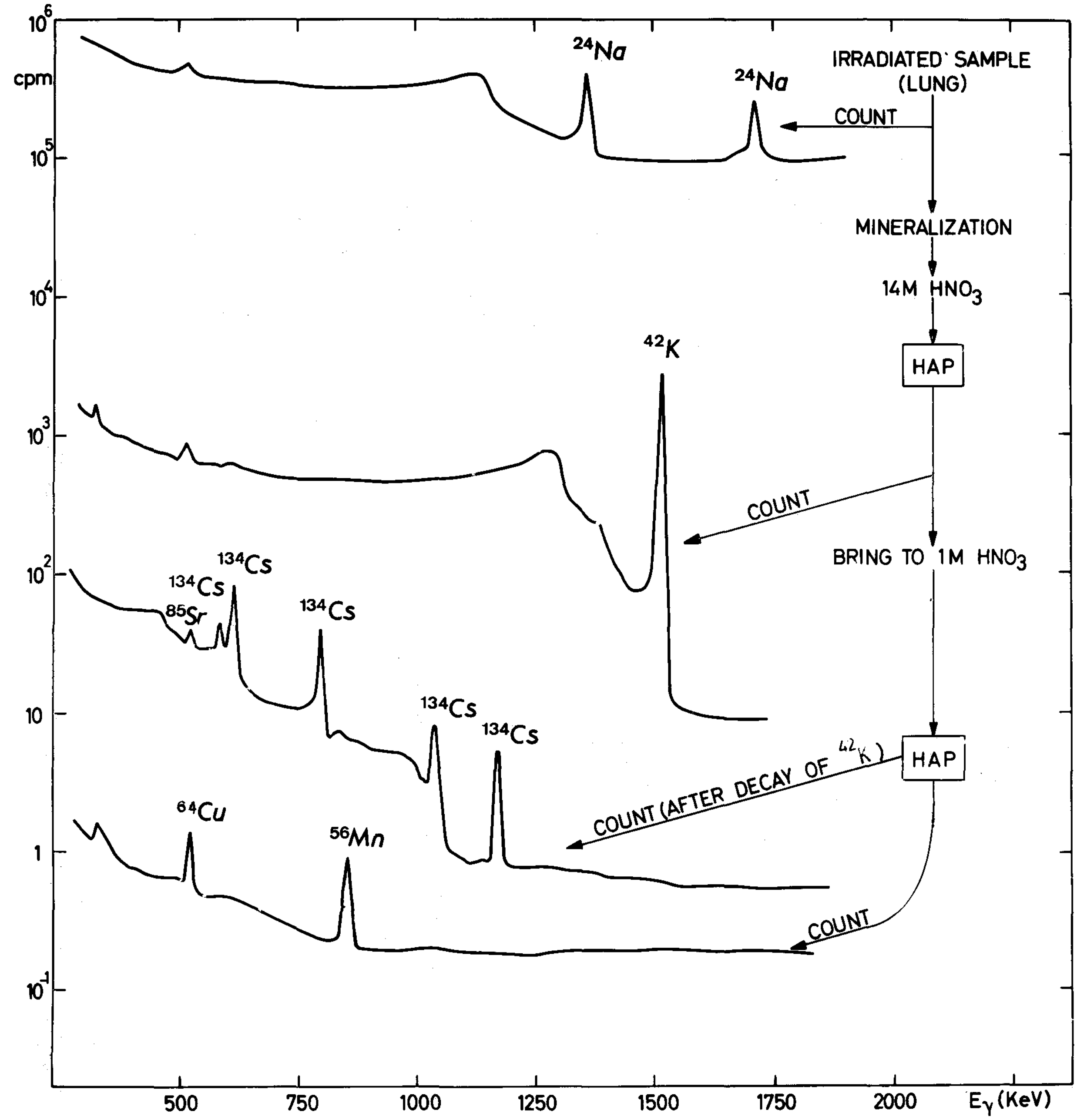

10^6
cpm
10^5
10^4
10^3
10^2
10
1
10^-1
500
750
1000
1250
1500
1750
2000
Eγ (KeV)
24Na
24Na
42K
134Cs
134Cs
85Sr
134Cs
134Cs
134Cs
64Cu
56Mn
IRRADIATED SAMPLE (LUNG)
COUNT
MINERALIZATION
14M HNO3
HAP
COUNT
BRING TO 1M HNO3
HAP
COUNT (AFTER DECAY OF 42K)
COUNT

Figure 6

3.5 Polyantimonic Acid (PAA)

3.5.1 Material

Commercial PAA (Applied Research, Belgium), was used. This material differs from HAP for a higher water content and a lower resistance to strong acide. By heating it to 270°C (drying temperature of HAP) a material identical to HAP is obtained.

3.5.2 Tracer experiments

Carried out in the following media:

a) 6 M HCl (33 ions): table 19 (PAA/6 Cl)

b) 7 M HNO_3 (32 ions): table 20 (PAA/7 N)

c)14 M HNO_3 (32 ions): table 21 (PAA/14 N)

3.5.3 Applications

Its behaviour is similar to that of HAP. It has a higher retention capacity, but its lower resistance to high HCl and $HClO_4$ molarities narrows its area of application.
No practical application was yet made.

3.5.4 References

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Report EUR 2497.e

27) Jean Lefebvre;
C.R.Acad.Sc.Paris, t. 260 (24 mai 1965).

28) Jean Lefebvre, François Gaymard;
C.R.Acad.Sc.Paris, t. 260 (28 juin 1967).

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J.Inorg.Nucl.Chem. 28, 2603 (1966).

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J.Inorg.Nucl.Chem. 30, 639 (1968).

POLYANTIMONIC ACID

6 M HCl

19(PAA/6Cl)

Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K	Ca	Sc ◕	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu	Zn ○	Ga	Ge	As	Se ●	Br
Rb ●	Sr ◕	Y	Zr ○	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ⌽	Cd	In ○	Sn ○	Sb ○	Te	I ○
Cs ◕	Ba ○	R.E. ○	Hf ○	Ta ●	W ○	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

POLYANTIMONIC ACID

7 M HNO_3

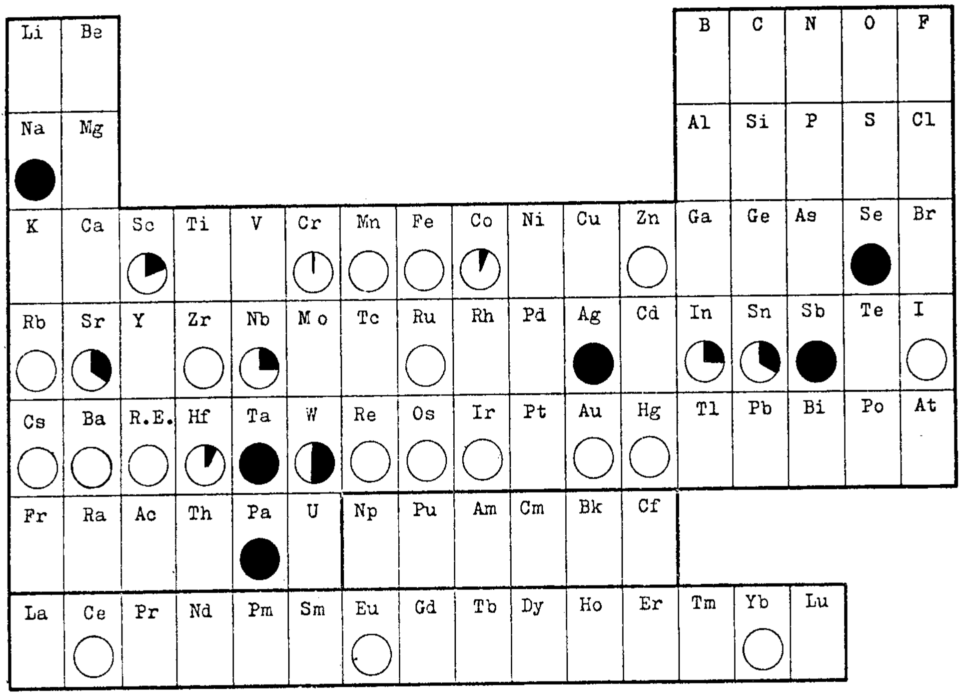
20(PAA/7N)

Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ●	Br
Rb ●	Sr ○	Y	Zr ○	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd	In ○	Sn ○	Sb ●	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

POLYANTIMONIC ACID

21(PAA/14N)

14 M HNO_3



Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K	Ca	Sc ◔	Ti	V	Cr ○	Mn ○	Fe ○	Co ◔	Ni	Cu	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ◔	Y	Zr ○	Nb ◔	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd	In ◔	Sn ◔	Sb ●	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ◔	Ta ●	W ◑	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

3.6 Antimony tetroxide (ATO)

3.6.1 Material

ATO was obtained from hydrated antimony pentoxide by heating it at 800-850°C.

3.6.2 Tracer experiments

Carried out in the following media:

a) 1 M HNO_3 (36 ions): table 22 (ATO/1N)

b) 6 M $HClO_4$(36 ions): table 23 (ATO/6P)

c) 6 M HF (36 ions): table 24 (ATO/6F)

d) 7 M HNO_3 (36 ions): table 25 (ATO/7N)

e)10 M HCl (36 ions): table 26 (ATO/10Cl)

f)14 M HNO_3 (36 ions): table 27 (ATO/14N)

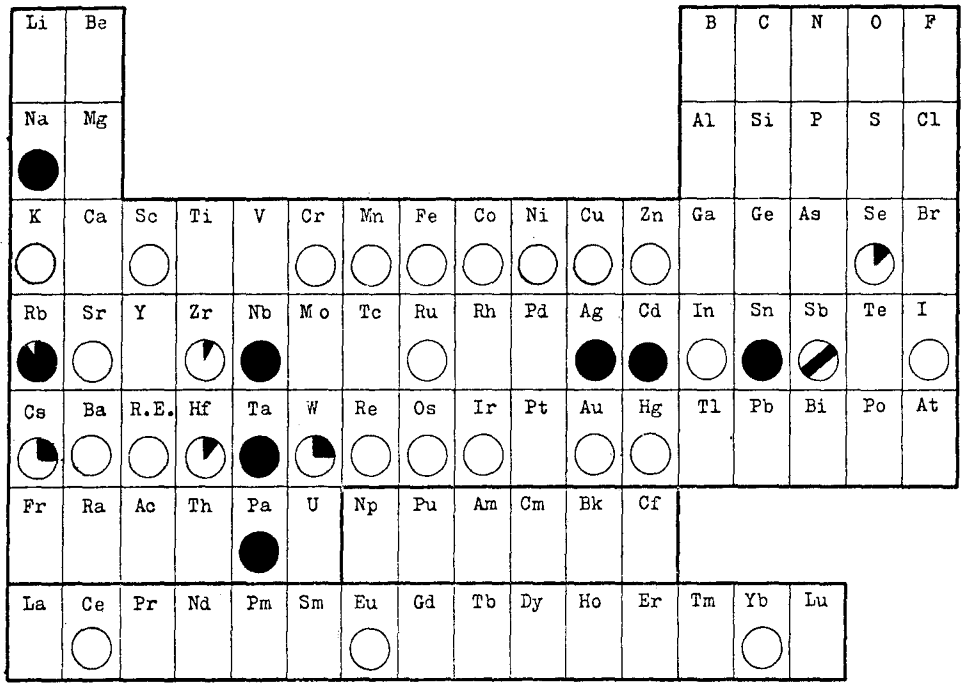
3.6.3 Applications

No special advantages were found over HAP. The retention capacity is lower. No application was therefore made.

ANTIMONY TETROXIDE

22(ATO/1N)

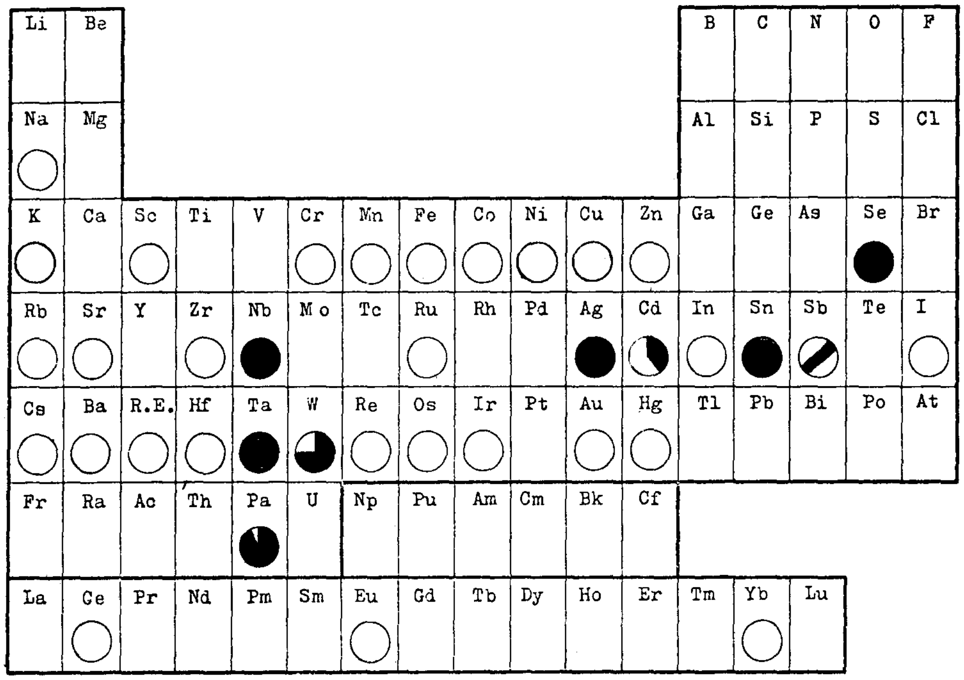
1 M HNO_3



ANTIMONY TETROXIDE

23(ATO/6P)

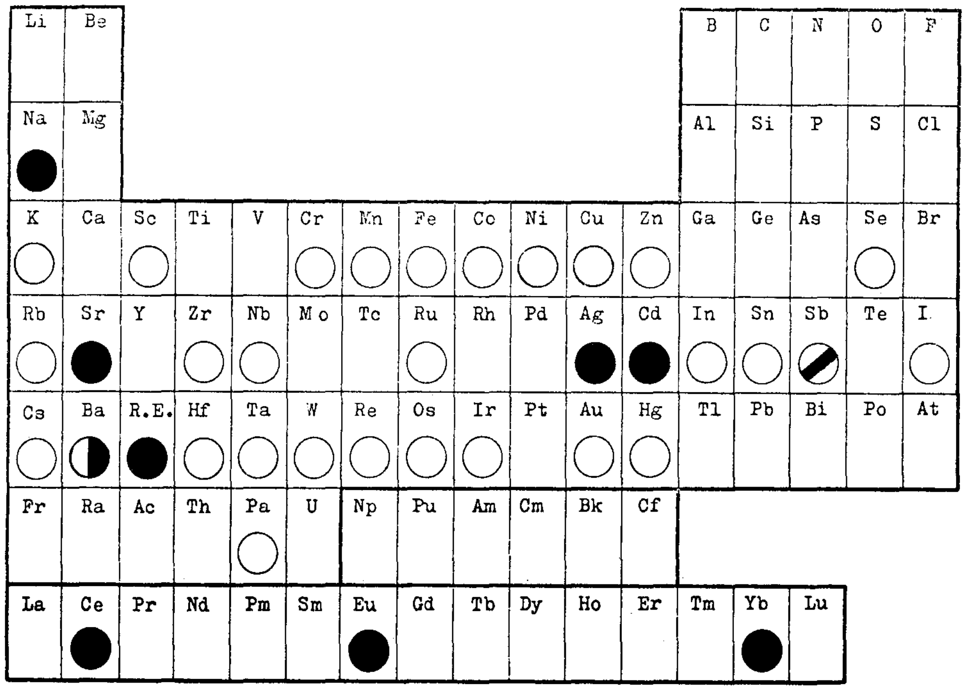
6 M $HClO_4$



ANTIMONY TETROXIDE

6 M HF

24(ATO/6F)

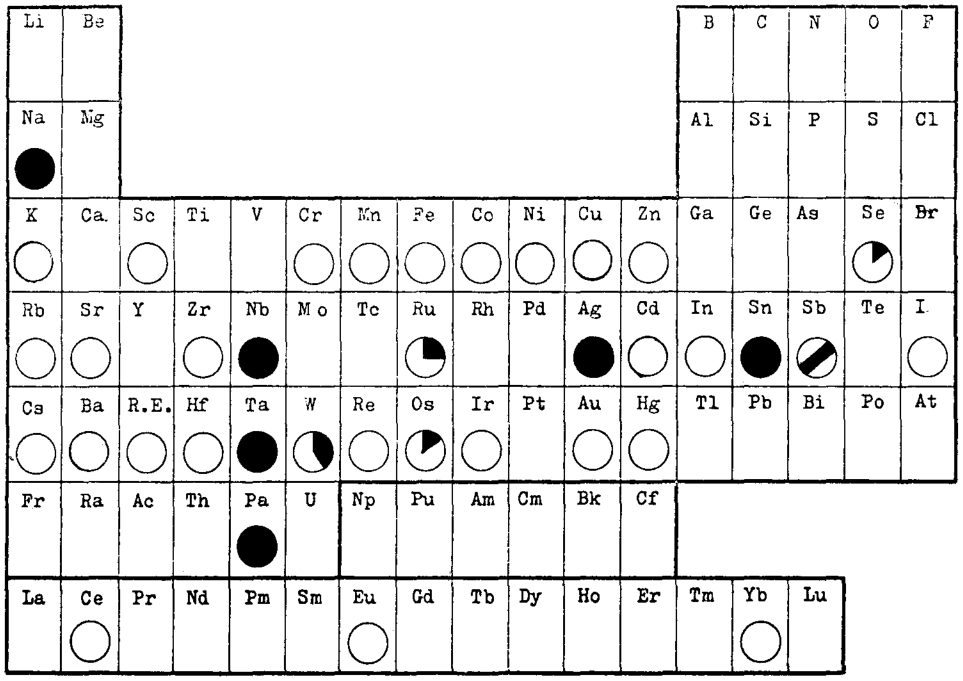


Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K ○	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ●	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd ●	In ○	Sn ○	Sb ⊘	Te	I ○
Cs ○	Ba ◑	R.E. ●	Hf ○	Ta ○	W ○	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ●	Pr	Nd	Pm	Sm	Eu ●	Gd	Tb	Dy	Ho	Er	Tm	Yb ●	Lu		

ANTIMONY TETROXIDE

7 M HNO_3

25(ATO/7N)



Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K ○	Ca 	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ◔	Br
Rb ○	Sr ○	Y	Zr ○	Nb ●	Mo	Tc	Ru ◔	Rh	Pd	Ag ●	Cd ○	In ○	Sn ●	Sb ⊘	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ◑	Re ○	Os ◔	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

ANTIMONY TETROXIDE

10 M HCl

26(ATO/10Cl)

Li	Be											B	C	N	O	F
Na ●	Mg											Al	Si	P	S	Cl
K ○	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ○	Y	Zr ○	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd ○	In ○	Sn ○	Sb ⊘	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ◔	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					

La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu

ANTIMONY TETROXIDE

14 M HNO_3

27(ATO/14N)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K ○	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ○	Y	Zr ○	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd ◔	In ○	Sn ●	Sb ⊘	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					

La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu

3.7 Cadmium oxide (CDO)

3.7.1 Material

Commercial cadmium oxide (Reagent grade R.P., Carlo Erba, Milan) was used.

CDO is soluble in strong acids. It is only slightly soluble in 0.1 M acids.

3.7.2 Tracer experiments

Carried out only in 0.1 M HNO_3 (59 ions): table 28 (CDO/0.1N).

3.7.3 Applications

CDO was used in the determination of Cs, Sr, and Rb in soils (see 3.10.3) and mollusks (see 3.9.3).

CADMIUM OXIDE

28(CDO/0.1N)

0.1 M HNO_3

Li	Be											B	C	N	O	F
Na ○	Mg ○											Al ●	Si	P ○	S ○	Cl ○
K ○	Ca ○	Sc ●	Ti ●	V ●	Cr ●	Mn ○	Fe ●	Co ○	Ni ○	Cu ●	Zn ●	Ga ●	Ge ●	As ●	Se ●	Br ○
Rb ○	Sr ○	Y	Zr ●	Nb ●	Mo ●	Tc ○	Ru ●	Rh	Pd ●	Ag ○	Cd ●	In ●	Sn ●	Sb ●	Te ●	I ○
Cs ○	Ba ○	R.E. ●	Hf ●	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt ○	Au ●	Hg ●	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U ○	Np ●	Pu	Am	Cm	Bk	Cf					
La ●	Ce ●	Pr	Nd ●	Pm ●	Sm	Eu ●	Gd	Tb ●	Dy	Ho	Er	Tm	Yb ●	Lu ●		

3.8 Acid Aluminium Oxide (AAO)

3.8.1 Material

Chromatographic acid aluminium oxide (activity grade 1, Woelm, Germany) was used.

3.8.2 Tracer experiments

Carried out in the following media:

a) 1 M $HClO_4$ (50 ions): table 29 (AAO/1P)

b) 1 M $HClO_4$ at 90°C (46 ions): table 30 (AAO/1P 90°C)

c) 1 M HNO_3 at 90°C (42 ions): table 31 (AAO/1N 90°C)

d) 7 M HNO_3 (48 ions): table 32 (AAO/7N)

e) 7 M HNO_3 at 90°C (42 ions): table 33 (AAO/7N 90°C).

3.8.3 Applications

AAO has been used frequently to prepare carrier-free ^{32}P from irradiated sulphur compounds. The selectivity obtained is good enough to make AAO a suitable filter for removing ^{32}P from irradiated samples (elimination of ^{32}P bremsstrahlung from gamma spectra).

Removal of ^{32}P was made:

a) From irradiated bone tissues, (5 mg) for the determination of Ba and Cr (in 5 cc of 1 M $HClO_4$ at 90°C), and for the determination of Cu and Mn (in 1 M $HClO_4$). An HAP column is connected in series to retain ^{24}Na and ^{42}K . ^{64}Cu and ^{56}Mn are eluted.

b) From leaf tissues, for the determination of Hg and Cr (in HNO_3 1 M and 7 M) (figure 7).

c) From fish muscle, for the determination of Na, K, Mn, Zn, Cs, Ba, Mg, Sr.

The irradiated sample, dissolved in fuming HNO_3 is directly passed on columns of AAO and HAP in series (removal of ^{32}P and ^{24}Na). The eluate is diluted to 0.1 M and passed on HMD at 70°C (removal of ^{56}Mn and ^{42}K). ^{69m}Zn, ^{134m}Cs, ^{27}Mg, ^{139}Ba and ^{87m}Sr are determined in the eluate.

3.8.4 References

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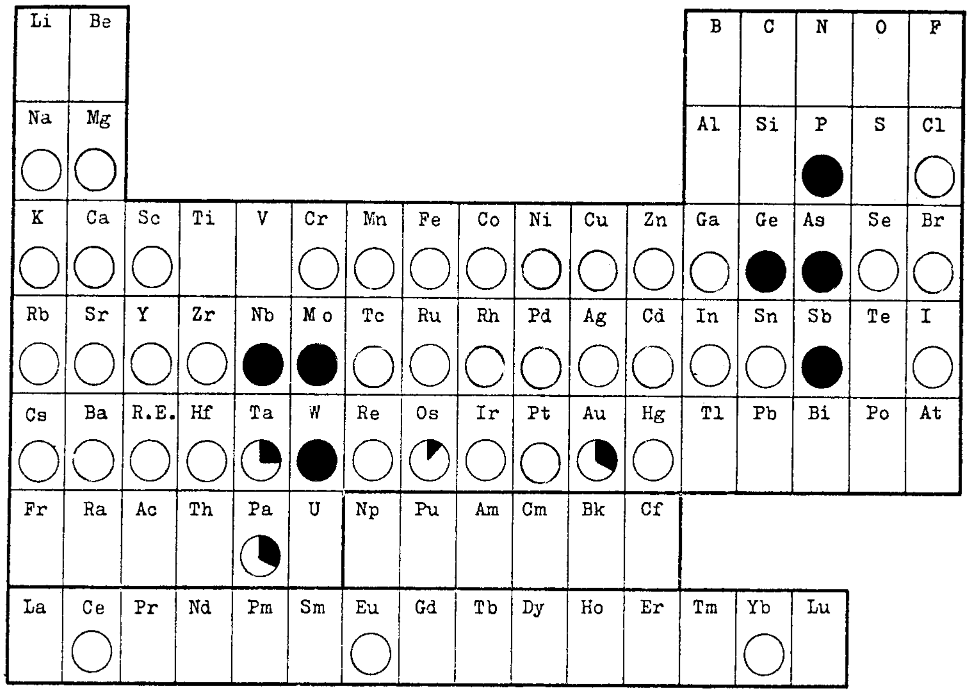
Report ORNL 2159.

ACID ALUMINIUM OXIDE

1 M $HClO_4$

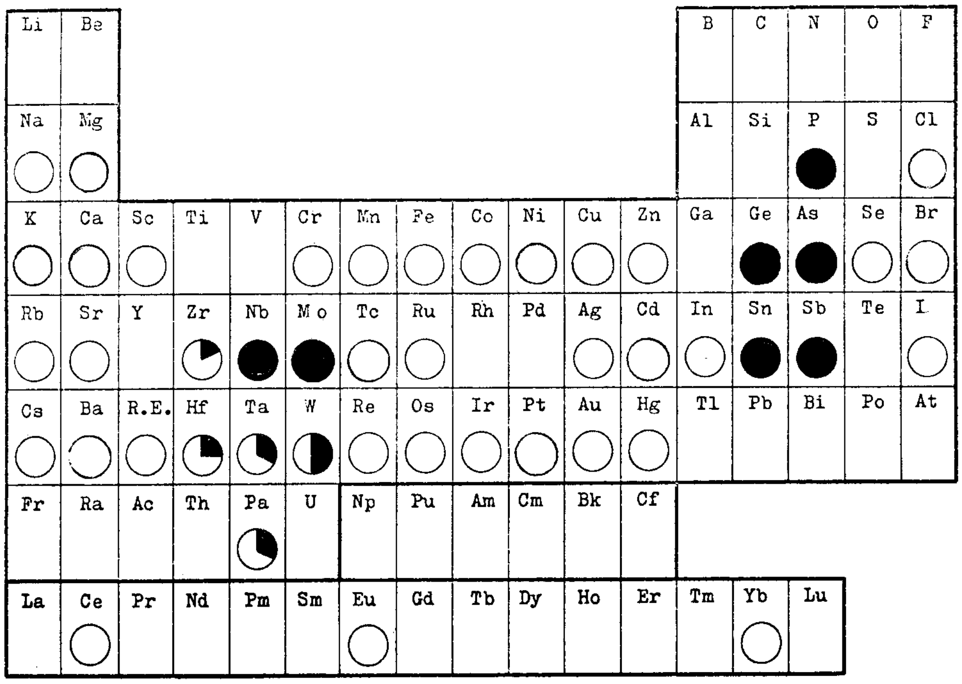
29(AAO/1P)



ACID ALUMINIUM OXIDE

1 M $HClO_4$ at 90°C

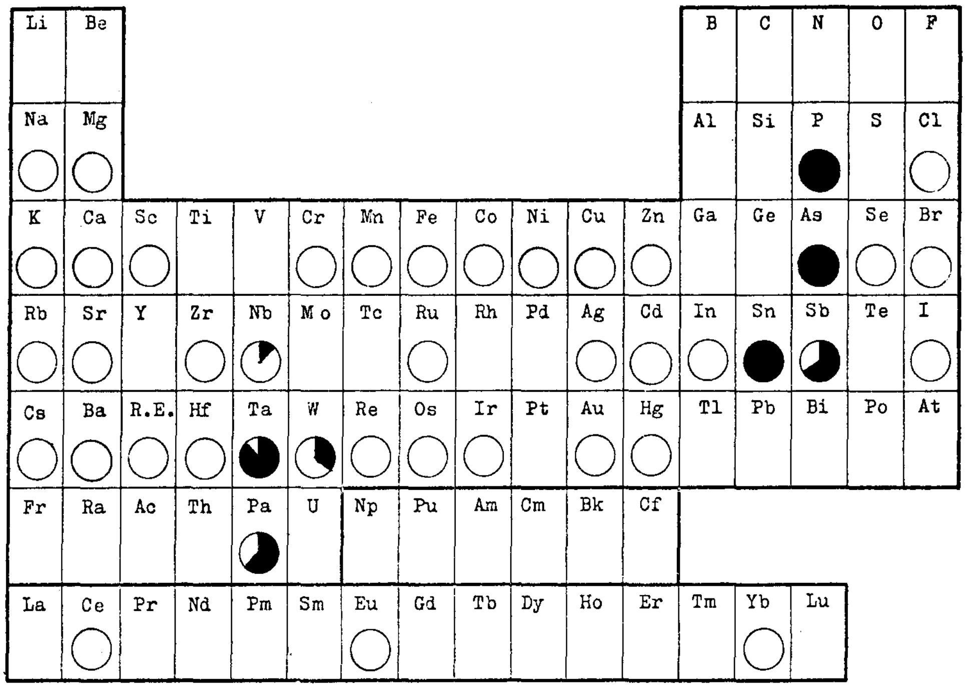
30(AAO/1P 90°C)



ACID ALUMINIUM OXIDE

1 M HNO_3 at 90°C

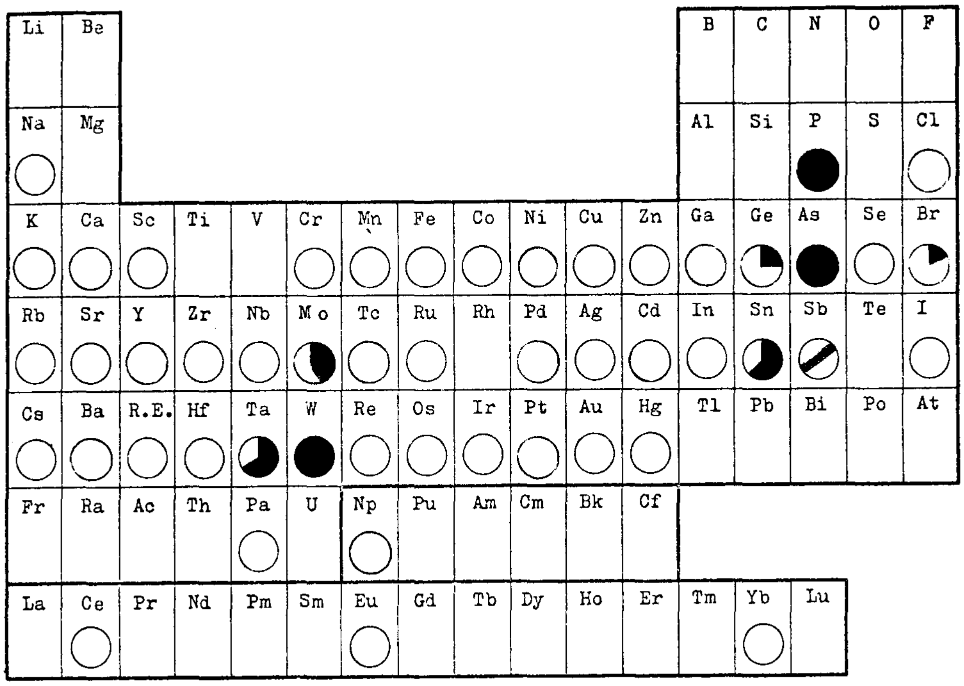
31(AAO/1N 90°C)



ACID ALUMINIUM OXIDE

7 M HNO_3

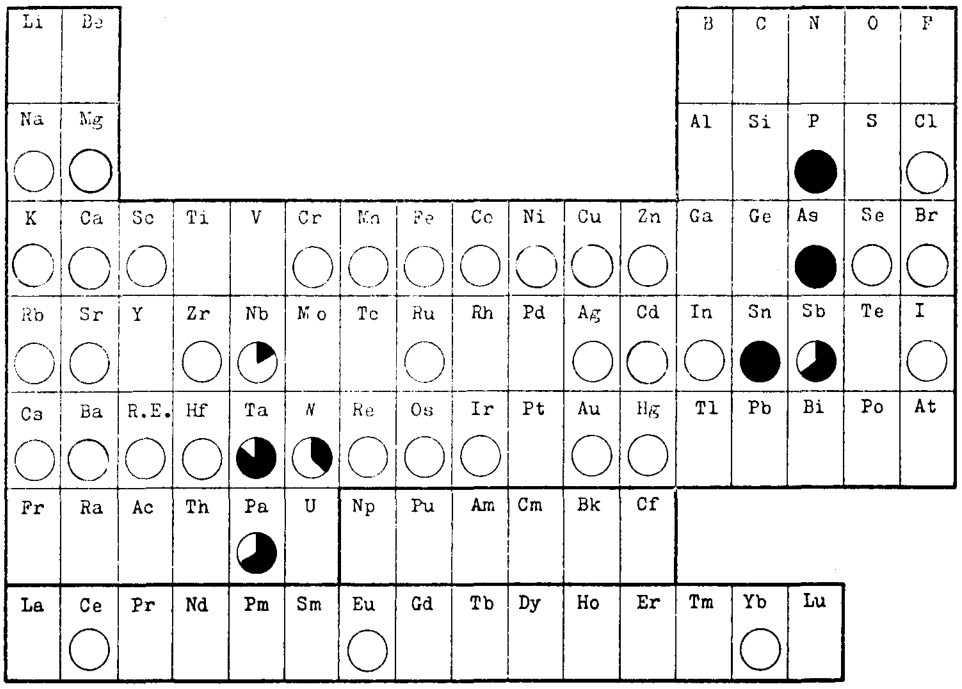
32(AAO/7N)



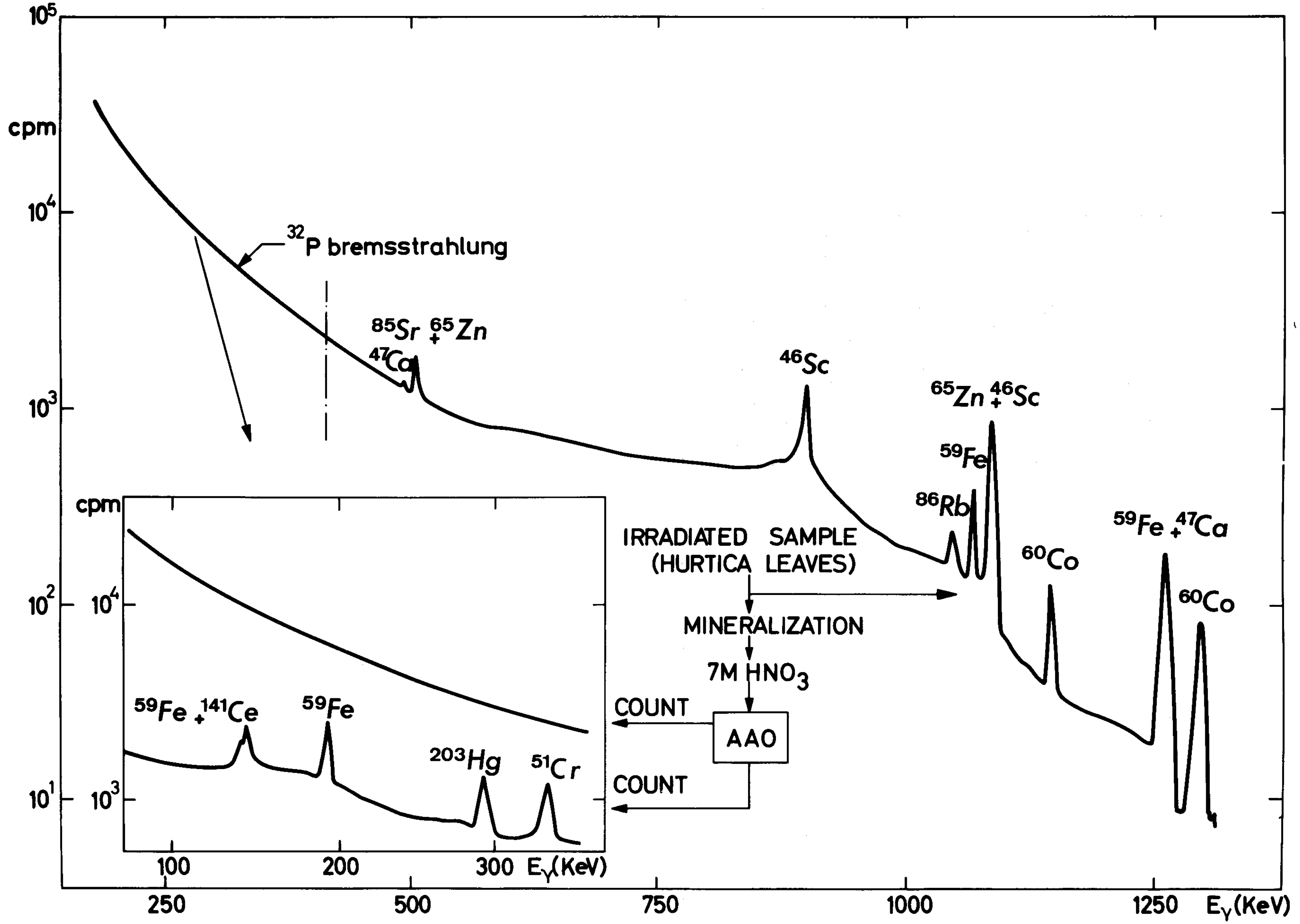
ACID ALUMINIUM OXIDE

33(AAO/7N 90°C)

7 M HNO_3 at 90°C



Li	Be											B	C	N	O	F
Na ○	Mg ○											Al	Si	P ●	S	Cl ○
K ○	Ca ○	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As ●	Se ○	Br ○
Rb ○	Sr ○	Y	Zr ○	Nb ◔	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd ○	In ○	Sn ●	Sb ◕	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ◕	W ◑	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ◕	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		



10^5
cpm
10^4
10^3
10^2
10^1
^{32}P bremsstrahlung
^{85}Sr + ^{65}Zn
^{47}Ca
^{46}Sc
^{65}Zn + ^{46}Sc
^{59}Fe
^{86}Rb
^{60}Co
^{59}Fe + ^{47}Ca
^{60}Co
250
500
750
1000
1250
E_γ(KeV)
cpm
10^4
10^3
^{59}Fe + ^{141}Ce
^{59}Fe
^{203}Hg
^{51}Cr
100
200
300
E_γ(KeV)
IRRADIATED SAMPLE
(HURTICA LEAVES)
MINERALIZATION
7M HNO_3
AAO
COUNT
COUNT

Figure 7

3.9 Tin dioxide (TDO)

3.9.1 Material

Commercial tin dioxide (Reagent grade RP, Carlo Erba, Milan) was used.

3.9.2 Tracer experiments

Carried out in the following media:

a) 0.1 M HNO_3 at 60°C (41 ions): table 34 (TDO/0.1N 60°C)
b) 1 M HCl (57 ions): table 35 (TDO/1 Cl)
c) 1 M HNO_3 (59 ions): table 36 (TDO/1N)
d) 1 M $HClO_4$ (47 ions): table 37 (TDO/1P)
e) 6 M HF (46 ions): table 38 (TDO/6F)
f) 7 M HNO_3 (56 ions): table 39 (TDO/7N)
g) 14 M HNO_3 (46 ions): table 40 (TDO/14N)

3.9.3 Applications

TDO was applied to:

a) Determination of Cs, Sr, Rb in mollusk soft tissues. The irradiated samples in 0.1 M HNO_3 are passed over TDO and CDO (removal of ^{59}Fe, ^{51}Cr, ^{46}Sc, ^{65}Zn, ^{122}Sb and ^{32}P). ^{134}Cs, ^{85}Sr and ^{86}Rb are found in the eluate. (figure 8).

b) Determination of Mo in mollusk shells.
The samples in 1 M HNO_3 are passed over TDO, Mo is retained. Major radioactivities are eluted.

c) An application to the determination of Cr in blood was reported in (22).

3.9.4 References

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TIN DIOXIDE

0.1 M HNO_3 at 60°C

34(TDO/0.1N 60°C)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ●	S	Cl ○
K ○	Ca	Sc ●	Ti	V	Cr ○	Mn ○	Fe ●	Co ○	Ni ○	Cu ○	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ○	Y	Zr ●	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd ○	In ●	Sn ●	Sb ●	Te	I ○
Cs ○	Ba ○	R.E. ○	Hf ●	Ta ●	W ●	Re ○	Os ●	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U ○	Np ●	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb ○	Dy	Ho	Er	Tm	Yb ○	Lu		

TIN DIOXIDE

1 M HCl

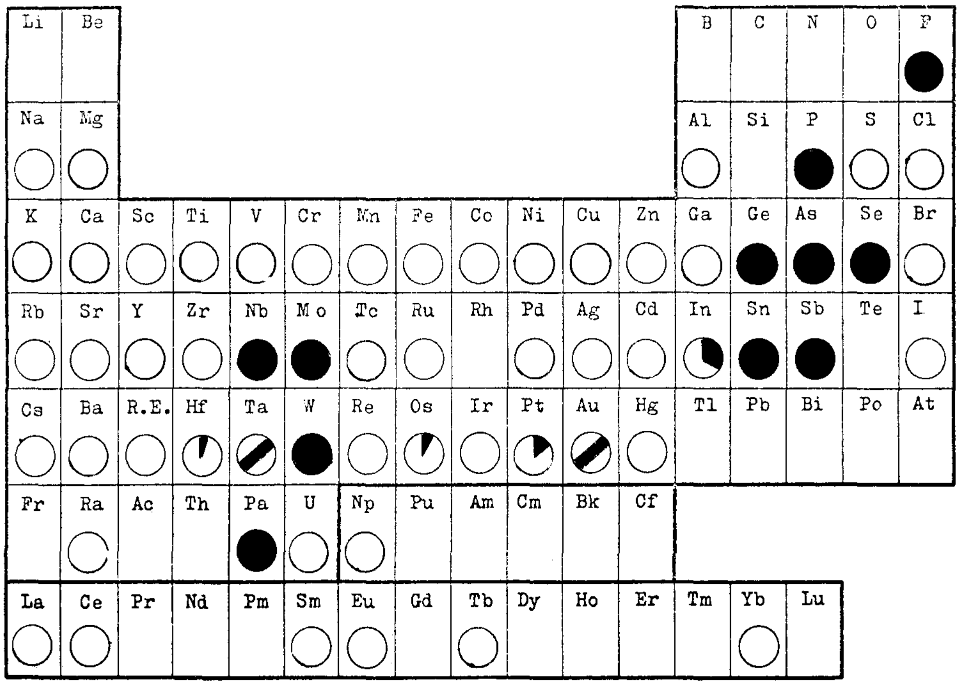
35(TDO/1Cl)

Li	Be											B	C	N	O	F ●
Na ○	Mg ○											Al ○	Si ●	P ○	S ○	Cl ○
K ○	Ca ○	Sc ○	Ti ○	V ○	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ●	As ●	Se ●	Br ○
Rb ○	Sr ○	Y ○	Zr ●	Nb ●	Mo ○	Tc ○	Ru ○	Rh	Pd ○	Ag ○	Cd ○	In ●	Sn ●	Sb ●	Te ○	I ○
Cs ○	Ba ○	R.E. ○	Hf ●	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt ○	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U ○	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

TIN DIOXIDE

1 M HNO_3

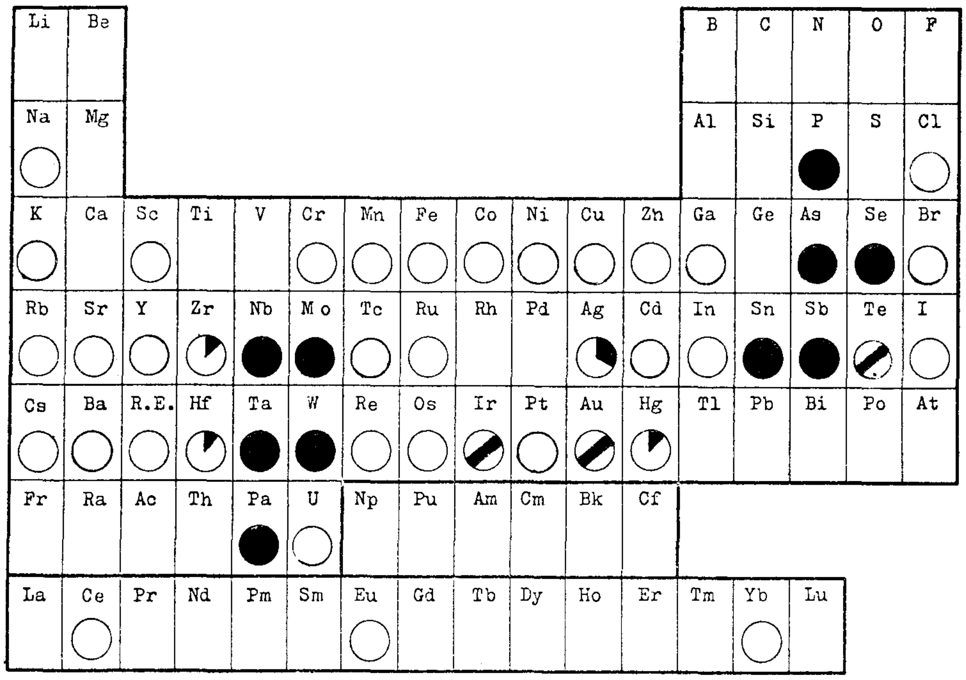
36(TDO/1N)



TIN DIOXIDE

1 M $HClO_4$

37(TDO/1P)



TIN DIOXIDE

6 M HF

38(TDO/6F)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ○	S	Cl ○
K ○	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge	As ●	Se ●	Br ○
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo ○	Tc ○	Ru ⊘	Rh	Pd	Ag ●	Cd ○	In ○	Sn ○	Sb ⊘	Te ⊘	I ○
Cs ○	Ba ○	R.E. ●	Hf ○	Ta ○	W ○	Re ○	Os ○	Ir ○	Pt ○	Au ●	Hg ⊘	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U ○	Np	Pu	Am	Cm	Bk	Cf					

La	Ce ●	Pr	Nd	Pm	Sm	Eu ●	Gd	Tb	Dy	Ho	Er	Tm	Yb ●	Lu

TIN DIOXIDE

7 M HNO_3

39(TDO/7N)

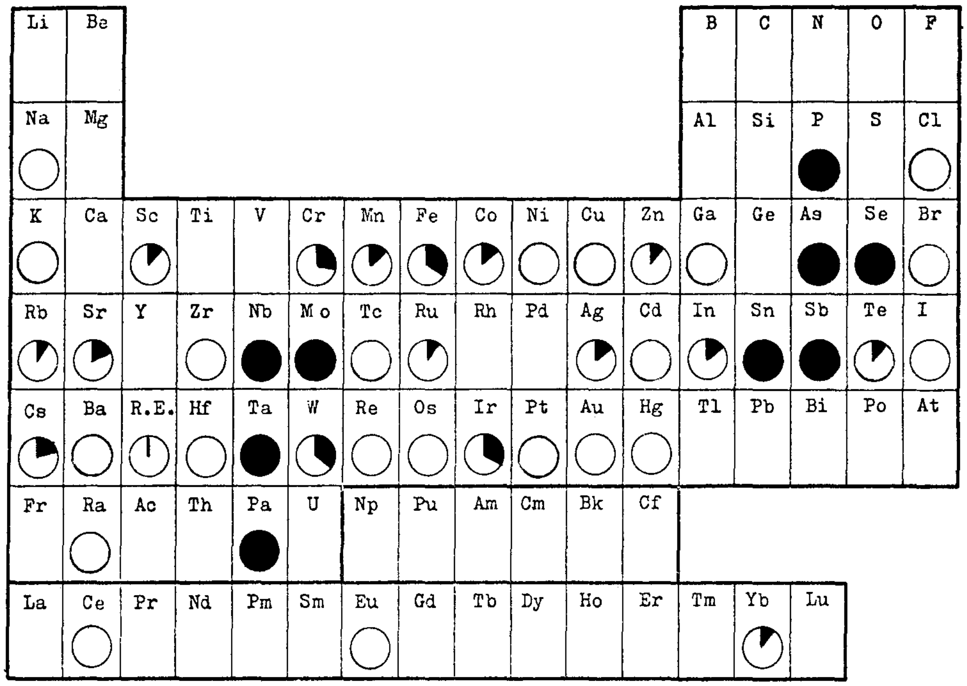
Li	Be											B	C	N	O	F ●
Na ○	Mg ○											Al ○	Si ●	P ●	S ○	Cl ○
K ○	Ca ○	Sc ○	Ti ○	V ○	Cr ○	Mn ○	Fe ○	Co ○	Ni ○	Cu ○	Zn ○	Ga ○	Ge ●	As ●	Se ●	Br ○
Rb ○	Sr ○	Y ○	Zr ○	Nb ●	Mo ●	Tc ○	Ru ○	Rh	Pd ○	Ag ◔	Cd ○	In ○	Sn ●	Sb ●	Te ◔	I ○
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt ○	Au ◔	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra ○	Ac	Th	Pa ●	U ○	Np ○	Pu	Am	Cm	Bk	Cf					

La ○	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu

TIN DIOXIDE

14 M HNO_3

40(TDO/14N)



Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ●	S	Cl ○
K ○	Ca	Sc ◔	Ti	V	Cr ◔	Mn ◔	Fe ◑	Co ◔	Ni ○	Cu ○	Zn ◔	Ga ○	Ge	As ●	Se ●	Br ○
Rb ◔	Sr ◔	Y	Zr ○	Nb ●	Mo ●	Tc ○	Ru ◔	Rh	Pd	Ag ◔	Cd ○	In ◔	Sn ●	Sb ●	Te ◔	I ○
Cs ◔	Ba ○	R.E. ○	Hf ○	Ta ●	W ◑	Re ○	Os ○	Ir ◑	Pt ○	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra ○	Ac	Th	Pa ●	U	Np	Pu	Am	Cm	Bk	Cf					

La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ◔	Lu

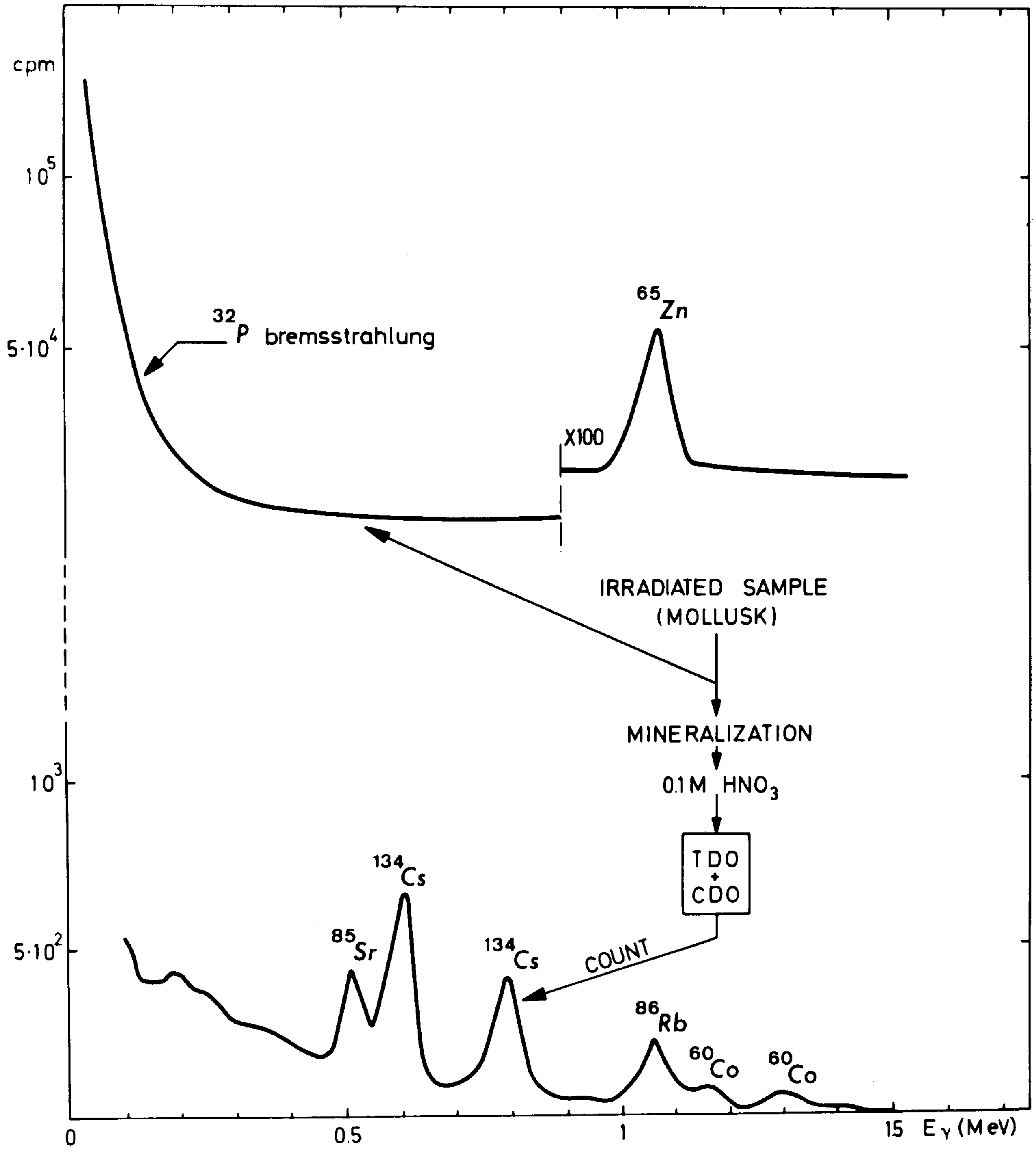

cpm
10^5
$5\cdot10^4$
10^3
$5\cdot10^2$
^{32}P bremsstrahlung
^{65}Zn
X100
IRRADIATED SAMPLE (MOLLUSK)
MINERALIZATION
0.1 M HNO_3
TDO + CDO
COUNT
^{85}Sr
^{134}Cs
^{134}Cs
^{86}Rb
^{60}Co
^{60}Co
0
0.5
1
1.5
E_γ (MeV)

Figure 8

3.10 Titanium phosphate (TPH)

3.10.1 Material

Acid titanium phosphate for chromatographic applications (Abedem TiA 50-100 S.E.R.A.I., Belgium) was used. The preparation and properties of the material are described in reference (41).

3.10.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 (34 ions): table 41 (TPH/1S)

b) 6 M HCl (38 ions): table 42 (TPH/6 Cl)

c) 6 M $HClO_4$ (38 ions): table 43 (TPH/6P)

d) 7 M HNO_3 (41 ions): table 44 (TPH/7N)

3.10.3 Applications

TPH was used with CDO to determine Cs, Sr and Rb in soil samples.

The irradiated sample (50 mg) in 5 cc of 0.1 M HNO_3 were passed on CDO (removal of major radioactivities), brought to 7 M HNO_3 and passed on TPH (^{86}Rb and ^{134}Cs are measured on the column, ^{85}Sr in the eluate).

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TITANIUM PHOSPHATE

1 M H_2SO_4

41(TPH/1S)

Li	Be											B	C	N	O	F
Na ◔	Mg											Al	Si	P ◑	S	Cl
K ●	Ca	Sc ●	Ti	V	Cr ○	Mn ○	Fe ◔	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ●	Br
Rb ●	Sr ○	Y	Zr ●	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ◑	Cd	In ◔	Sn ●	Sb ●	Te	I ○
Cs ●	Ba	R.E. ○	Hf ⊘	Ta ●	W ●	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np ◔	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

TITANIUM PHOSPHATE

6 M HCl

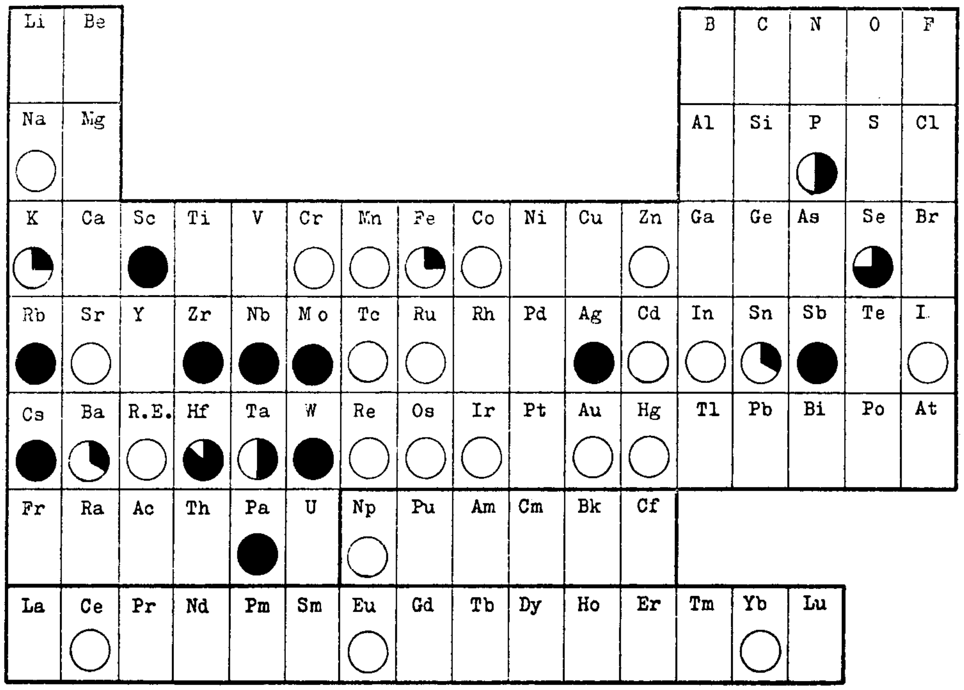
42(TPH/6Cl)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ◑	S	Cl
K ●	Ca	Sc ◕	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ◕	Br
Rb ●	Sr ○	Y	Zr ○	Nb ●	Mo ○	Tc ○	Ru ○	Rh	Pd	Ag ○	Cd ○	In ○	Sn ○	Sb ○	Te	I ○
Cs ●	Ba ◔	R.E. ○	Hf ◑	Ta ●	W ◕	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np ◑	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

TITANIUM PHOSPHATE

6 M $HClO_4$

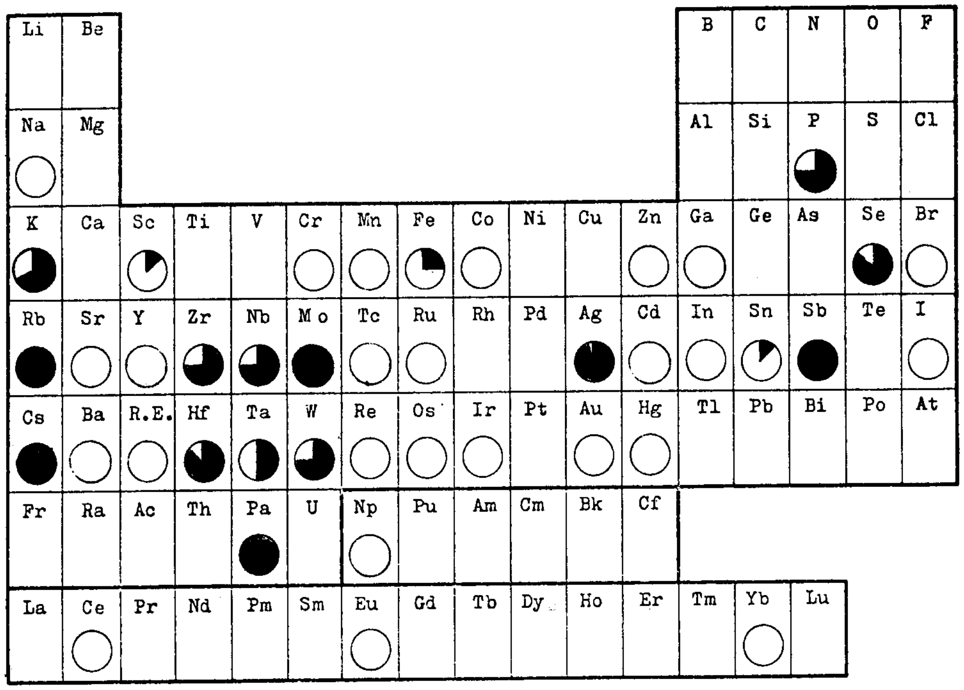
43(TPH/6P)



TITANIUM PHOSPHATE

7 M HNO_3

44(TPH/7N)



3.11 Zirconium phosphate (ZPH)

3.11.1 Materials

Two commercial products for chromatographic applications (ZP BioRad, USA, Zirconium phosphate "Applied Research SPRL", Belgium) were used.

3.11.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 on BioRad (35 ions): table 45 (ZPH BioRad/1S)
b) 6 M HCl on BioRad (32 ions): table 46 (ZPH BioRad/6Cl)
c) 6 M HCl on Appl.Res.(33 ions): table 47 (ZPH Appl.Res./6Cl)
d) 6 M $HClO_4$ on BioRad (33 ions): table 48 (ZPH BioRad/6P)
e) 6 M $HClO_4$ on Appl.Res.(34 ions): table 49 (ZPH Appl.Res./6P)
f) 7 M HNO_3 on BioRad (36 ions): table 50 (ZPH BioRad/7N)
g) 7 M HNO_3 on Appl.Res.(34 ions): table 51 (ZPH Appl.Res./7N)

3.11.3 Applications

ZPH has long been used for fission products separation, and much literature is available. No application has yet been made by us.

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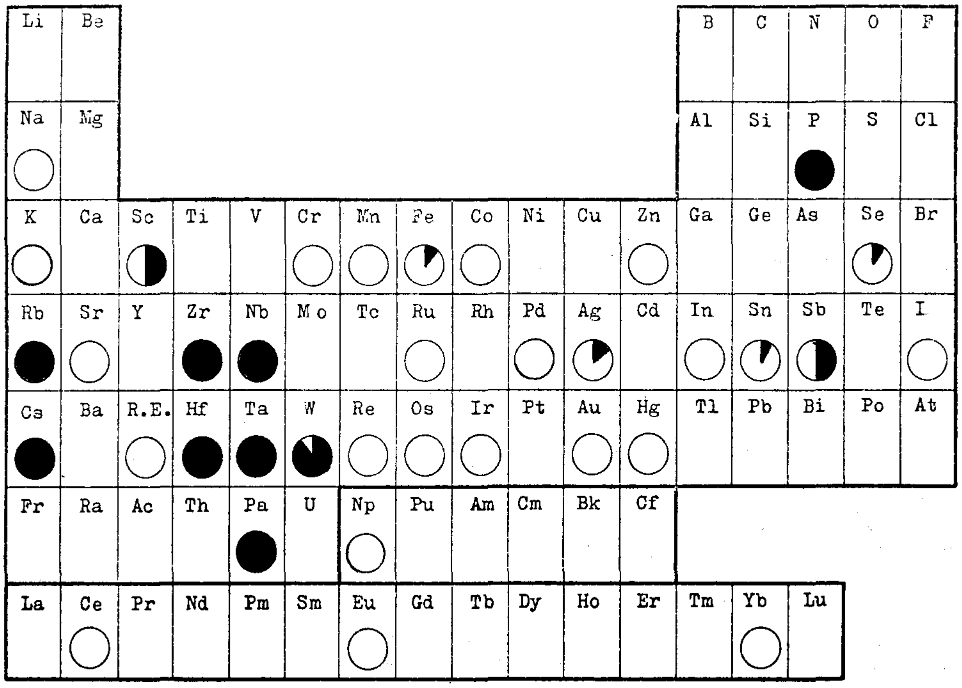
ZIRCONIUM PHOSPHATE (BioRad)

1 M H_2SO_4

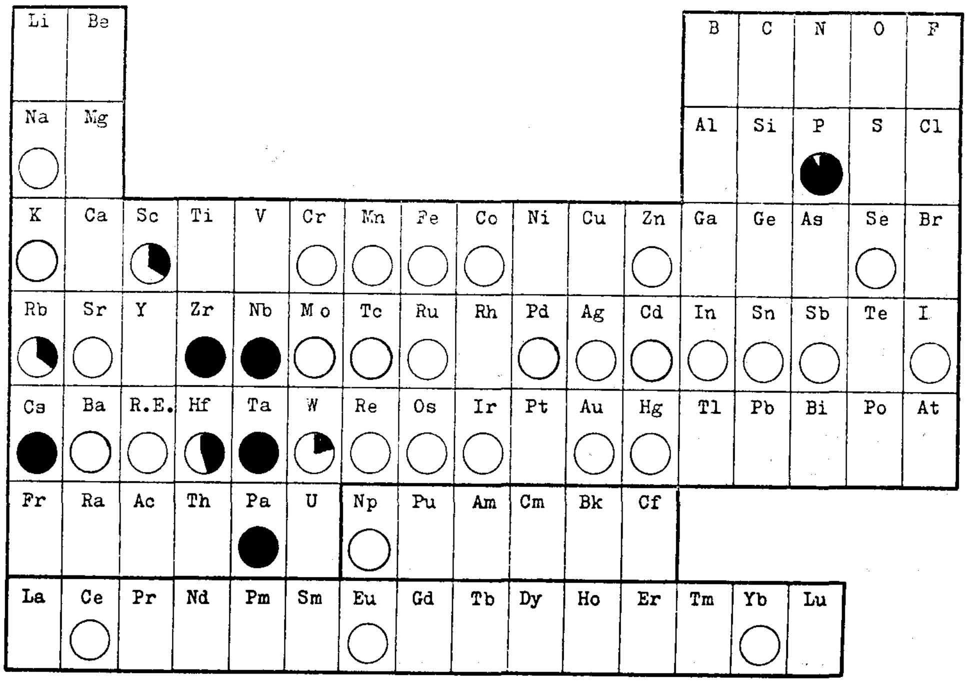
45(ZPH BioRad/1S)



ZIRCONIUM PHOSPHATE (BioRad)

6 M HCl

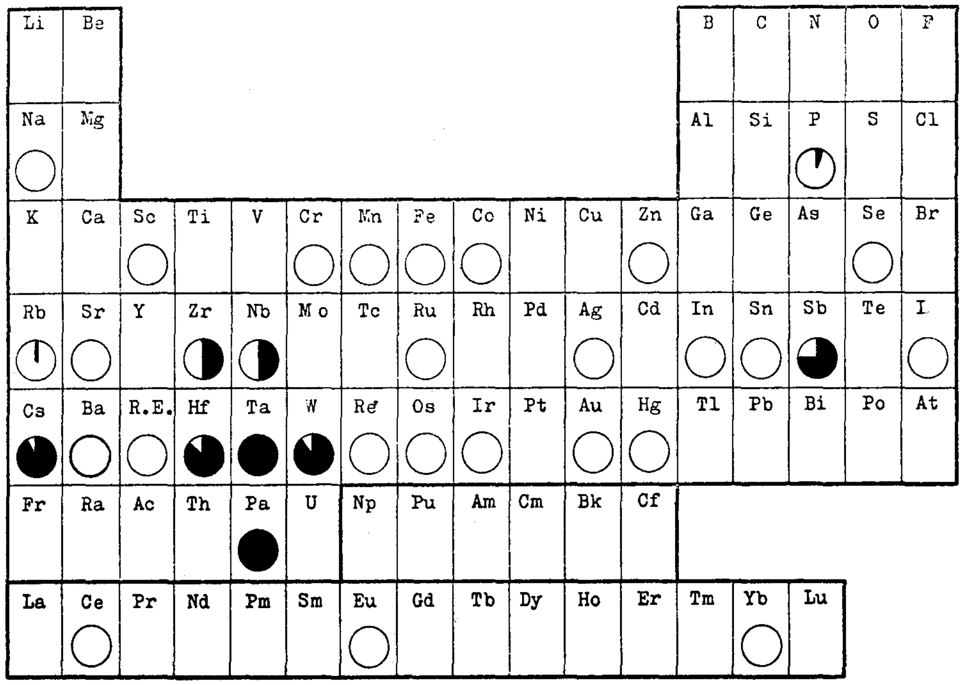
46(ZPH BioRad/6Cl)



ZIRCONIUM PHOSPHATE (Appl.Res.)

6 M HCl

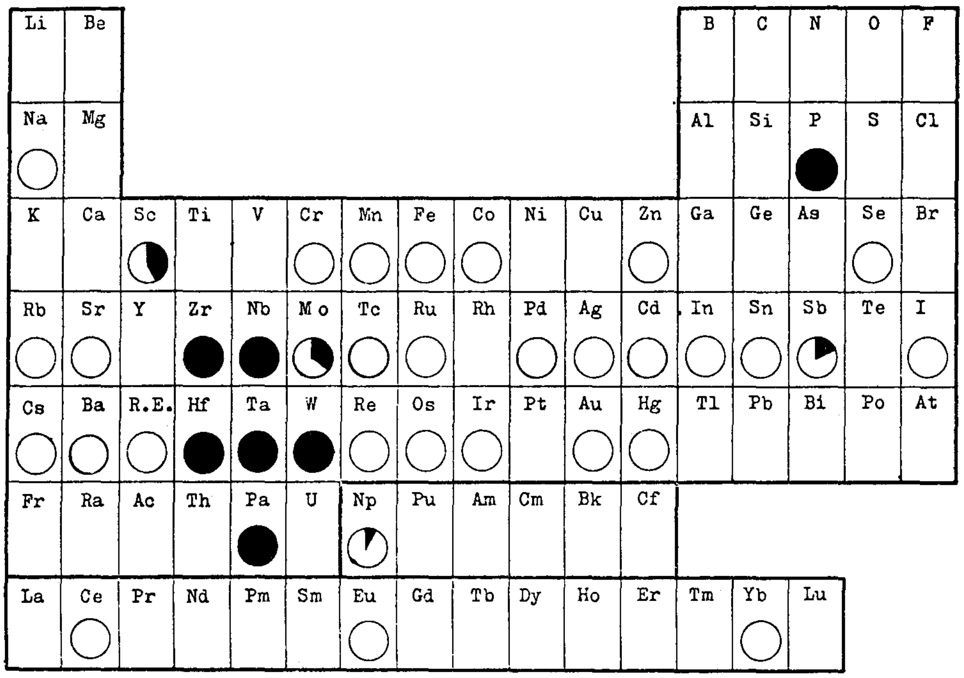
47(ZPH Appl.Res./6Cl)



ZIRCONIUM PHOSPHATE (BioRad)

6 M $HClO_4$

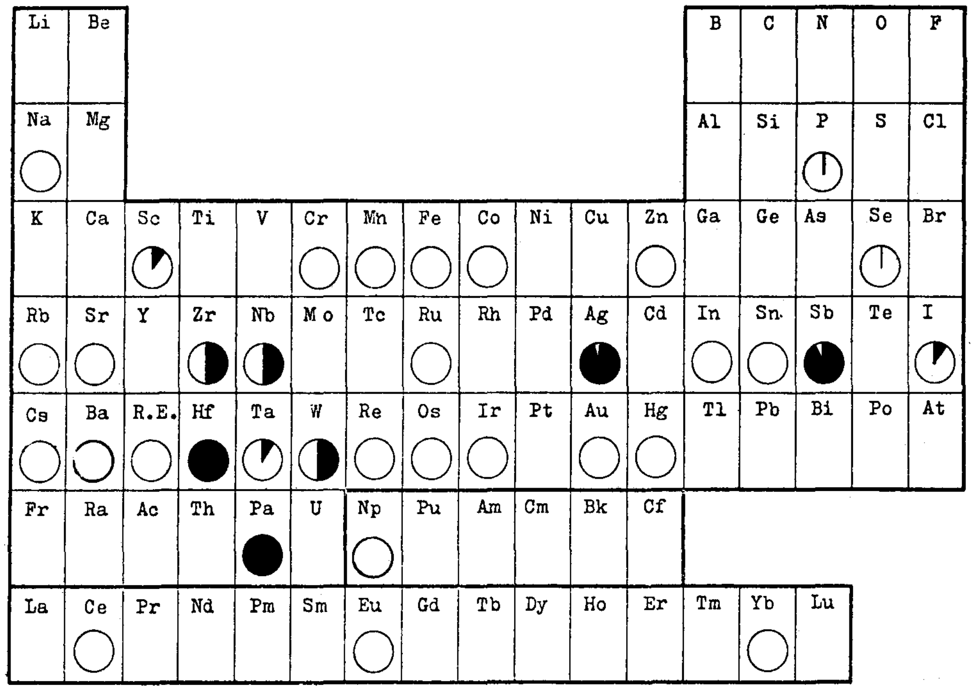
48(ZPH BioRad/6P)



ZIRCONIUM PHOSPHATE (Appl.Res.)

6 M $HClO_4$

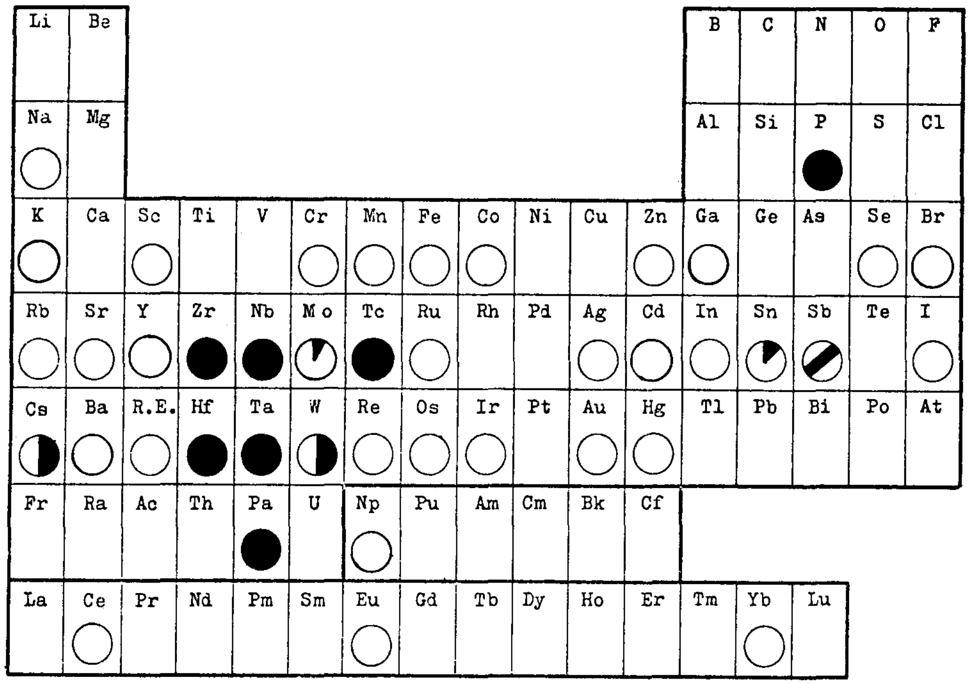
49(ZPH Appl.Res./6P)



ZIRCONIUM PHOSPHATE (BioRad)

7 M HNO_3

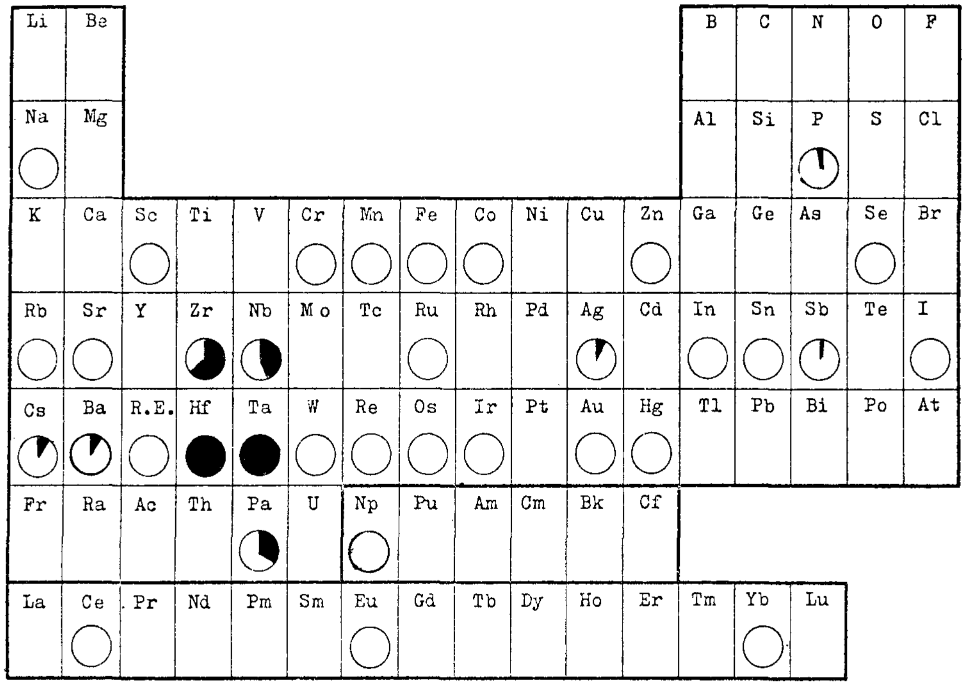
50(ZPH BioRad/7N)



ZIRCONIUM PHOSPHATE (Appl.Res.)

7 M HNO_3

51(ZPH Appl.Res./7N)



Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ◔	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ◕	Nb ◑	Mo	Tc	Ru ○	Rh	Pd	Ag ◔	Cd	In ○	Sn ○	Sb ◔	Te	I ○
Cs ◔	Ba ◔	R.E. ○	Hf ●	Ta ●	W ○	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ◑	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

3.12 Stannic Phosphate (SPH)

3.12.1 Material

Commercial SPH for chromatographic applications (Abedem Sn 50-100 S.E.R.A.I. Belgium) was used.

3.12.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 (33 elements): table 52 (SPH/1S)

b) 6 M $HClO_4$ (33 elements): table 53 (SPH/6P)

c) 7 M HNO_3 (34 elements): table 54 (SPH/7N)

3.12.3 Applications

The behaviour of tin phosphate seems less interesting than that of the Zr and Ti phosphate, at least in the limited amount of experiments done. No practical application was attempted.

3.12.4 References

87) J.Piret, J.Henry, G.Balon and C.Beaudet;
Bull.Soc.Chimique de France 12, 3590 (1965).

88) Yasushi Inove;
J.Inorg.Nucl.Chem. 26, 2241 (1964).

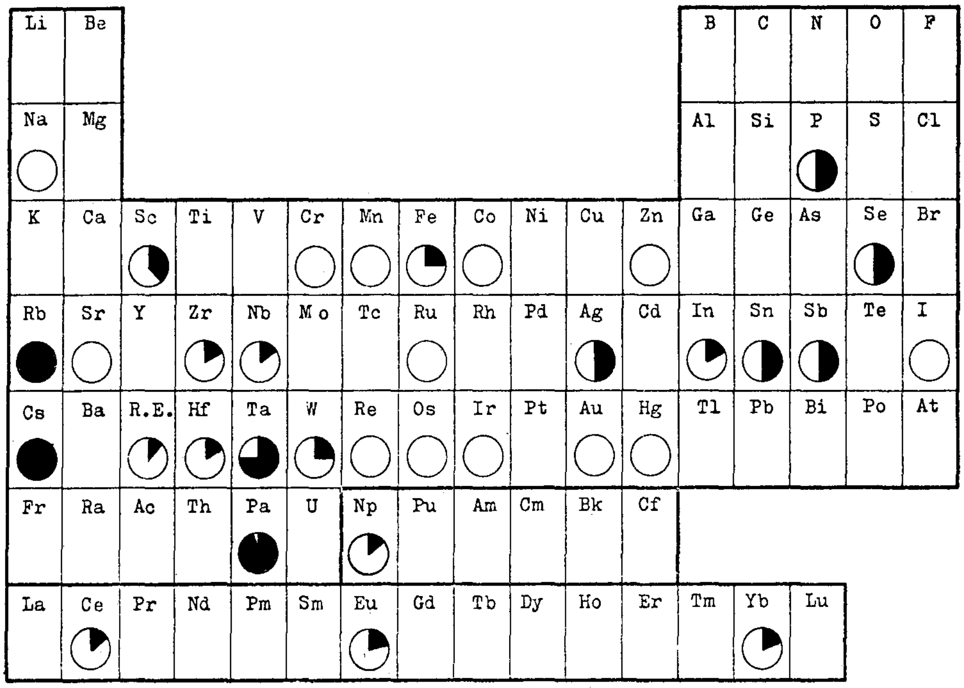
89) Yvonne M.Jones;
Report BNWL 270.

90) E.Merz;
Report CEA-tr. A-715.

STANNIC PHOSPHATE

52(SPH/1S)

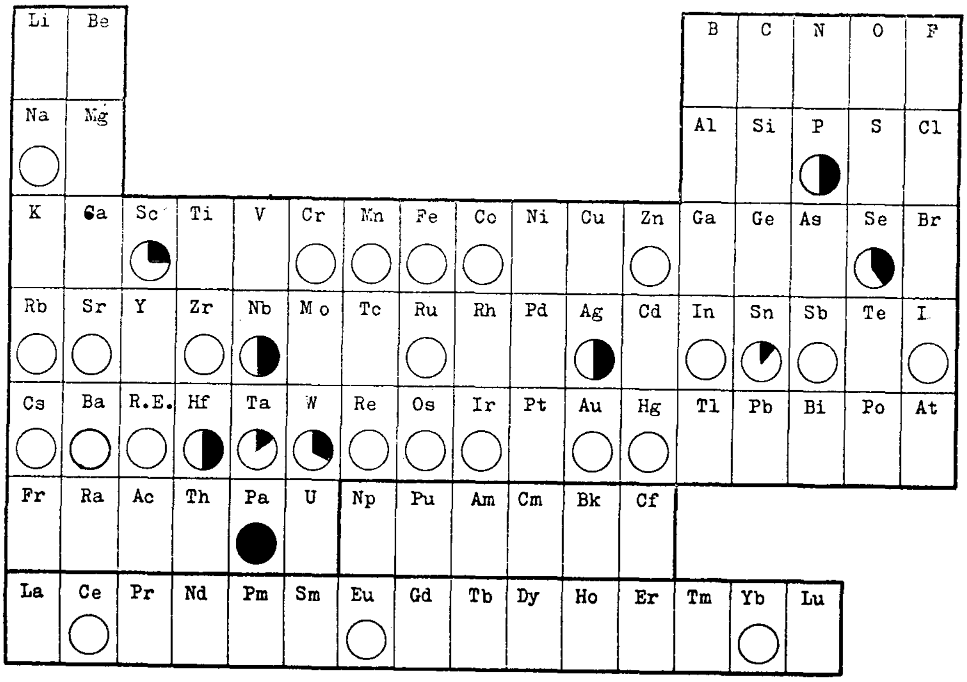
1 M H_2SO_4



STANNIC PHOSPHATE

53(SPH/6P)

6 M $HClO_4$



STANNIC PHOSPHATE

7 M HNO_3

54(SPH/7N)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ○	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ◔	Br
Rb ⌽	Sr ○	Y	Zr ○	Nb ●	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd	In ○	Sn ○	Sb ○	Te	I ○
Cs ◔	Ba ○	R.E. ○	Hf ◔	Ta ◕	W ○	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np ◔	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

3.13 Cupric sulphide (CUS)

3.13.1 Material

Reagent grade cupric sulphide (L.R., BDH, United Kingdom) was used. 15 ml of the eluent were used for the preliminary washing of the prepared column, to remove traces of copper sulphate formed by air oxidation of the sulphide.

3.13.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 (33 ions): table 55 (CUS/1S)

b) 6 M HCl (34 ions): table 56 (CUS/6Cl)

c) 6 M $HClO_4$ (34 ions): table 57 (CUS/6P)

d) 7 M HNO_3 (34 ions): table 58 (CUS/7N)

3.13.3 Applications

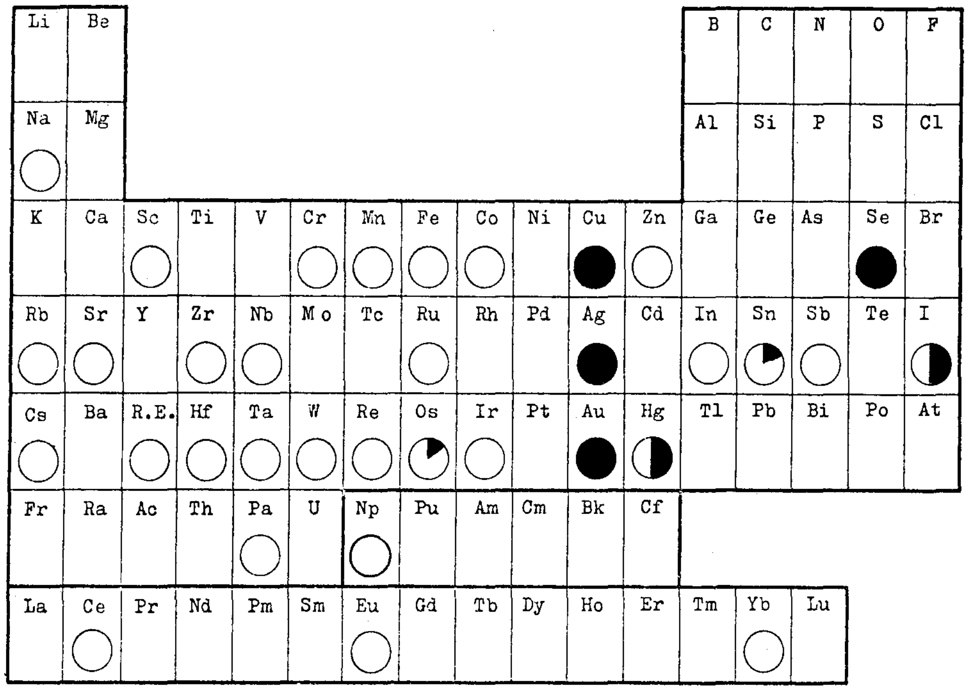
CUS is fairly selective for retaining Cu, Ag, Au, Se in most media.

Its behaviour is similar to that of CuCl (see 3.14).

CUPRIC SULPHIDE

1 M H_2SO_4

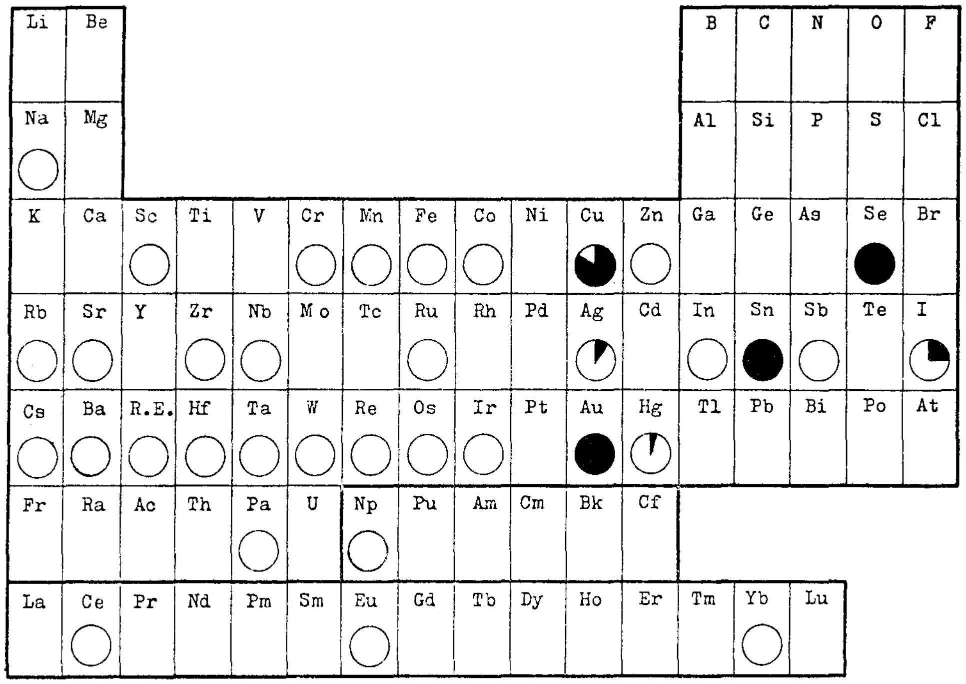
55(CUS/1S)



CUPRIC SULPHIDE

6 M HCl

56(CUS/6Cl)



CUPRIC SULPHIDE

6 M $HClO_4$

57(CUS/6P)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu ●	Zn ○	Ga	Ge	As	Se ●	Br
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd	In ○	Sn ◑	Sb ○	Te	I ●
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ○	W ◑	Re ○	Os ○	Ir ⊘	Pt	Au ●	Hg ⊘	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

CUPRIC SULPHIDE

7 M HNO_3

58(CUS/7N)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu ○	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ◔	Cd	In ○	Sn ○	Sb ○	Te	I ●
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ○	W ○	Re ○	Os ○	Ir ○	Pt	Au ○	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

3.14 Cuprous chloride (CUC)

3.14.1 Material

Reagent grade cuprous chloride ("Analar", BDH, United Kingdom) was used.

15 ml of eluent were used for the preliminary washing of the prepared columns, to remove traces of cupric chloride formed by air oxidation of cuprous chloride.

3.14.2 Tracer experiments

Carried out from the following media:

a) 1 M H_2SO_4 (34 elements): table 59 (CUC/1S)

b) 6 M $HClO_4$ (36 elements): table 60 (CUC/6P)

c) 6 M HF (36 elements): table 61 (CUC/6F)

3.14.3 Applications

CUC mainly differs from CUS by a different solubility in acid media.

It was used for the determination of copper:

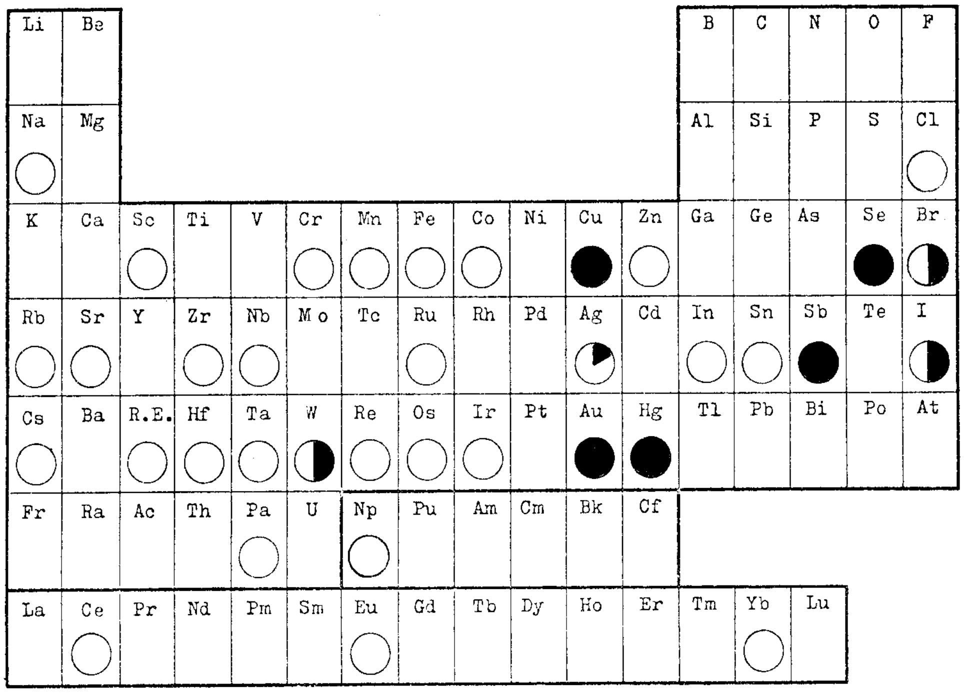
a) in bones (15 mg): from 7 cc of 1 M H_2SO_4 (^{64}Cu measured on the column, ^{24}Na removed, a partial precipitation of Ca SO_4 did not affect the separation).

b) in aluminium (50 mg): from 5 cc of 6 M $HClO_4$ (^{64}Cu measured on the column, ^{24}Na, ^{56}Mn, ^{72}Ga eluted).

CUPROUS CHLORIDE

1 M H_2SO_4

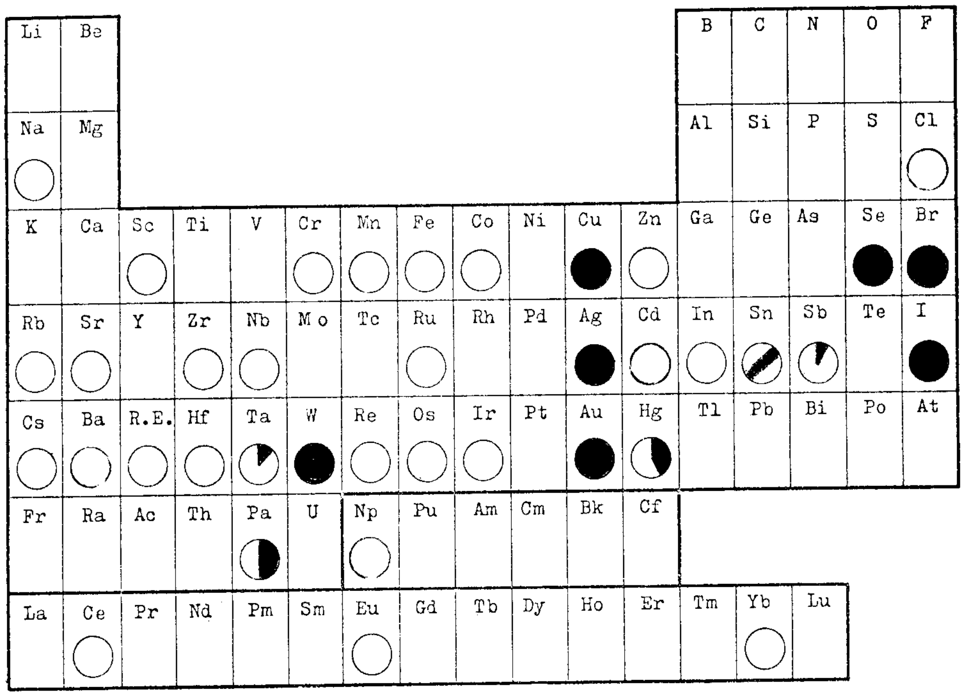
59(CUC/1S)



CUPROUS CHLORIDE

6 M $HClO_4$

60(CUC/6P)



CUPROUS CHLORIDE

6 M HF

61(CUC/6F)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl ○
K	Ca	Sc ◔	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu ●	Zn ○	Ga	Ge	As	Se ●	Br ●
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ●	Cd ○	In ○	Sn ○	Sb ○	Te	I ●
Cs ○	Ba ○	R.E. ●	Hf ○	Ta ○	W ○	Re ○	Os ○	Ir ○	Pt	Au ●	Hg ◕	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np ◔	Pu	Am	Cm	Bk	Cf					
La	Ce ●	Pr	Nd	Pm	Sm	Eu ●	Gd	Tb	Dy	Ho	Er	Tm	Yb ●	Lu		

3.15 Cadmium sulphide (CDS)

3.15.1 Material

Reagent grade CdS ("L.R.", B.D.H., United Kingdom) was used.

3.15.2 Tracer experiments

Carried out from 6 M HF (36 elements): table 62 (CDS/6F).

3.15.3 Applications

The behaviour of CDS does not seem particularly interesting. Among all materials which were tested, it was the only one which retained rhenium. No practical application was made.

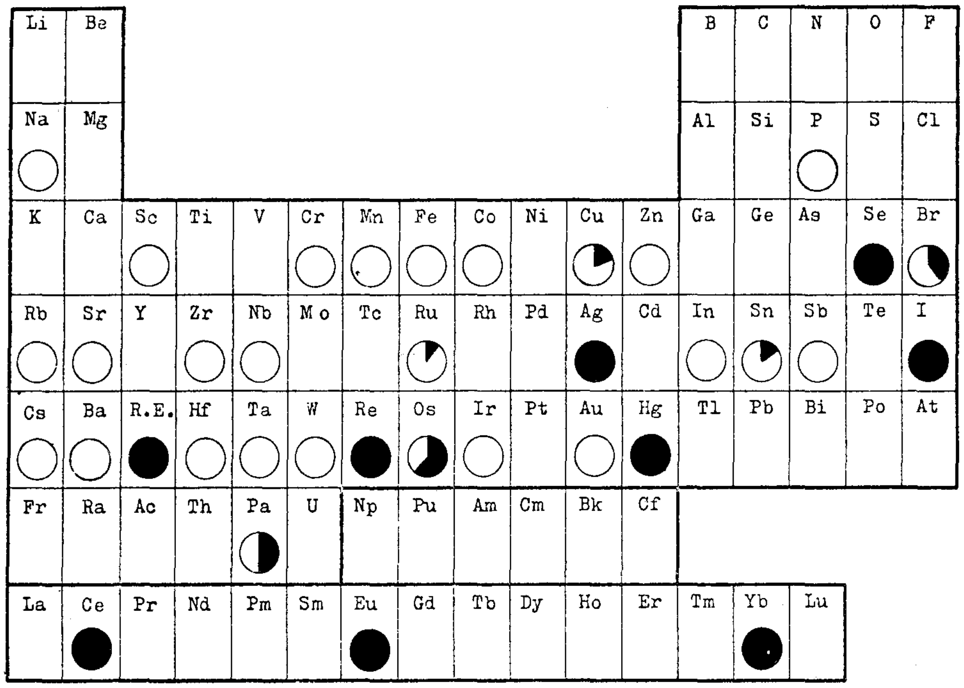
3.15.4 References

91) Harold O.Phillips, Kurt A.Kraus;
J.Am.Chem.Soc. 85, 481 (1963).

CADMIUM SULPHIDE

6 M HF

62(CDS/6F)



Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P ○	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu ◔	Zn ○	Ga	Ge	As	Se ●	Br ◔
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ◔	Rh	Pd	Ag ●	Cd	In ○	Sn ◔	Sb ○	Te	I ●
Cs ○	Ba ○	R.E. ●	Hf ○	Ta ○	W ○	Re ●	Os ◕	Ir ○	Pt	Au ○	Hg ●	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ◑	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ●	Pr	Nd	Pm	Sm	Eu ●	Gd	Tb	Dy	Ho	Er	Tm	Yb ●	Lu		

3.16 Lead fluoride (LDF)

3.16.1 Material

Reagent grade PbF ("L.R.", grade, BDH, United Kingdom) was used.

3.16.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 (32 ions): table 63 (LDF/1S)

b) 6 M HF (32 ions): table 64 (LDF/6F)

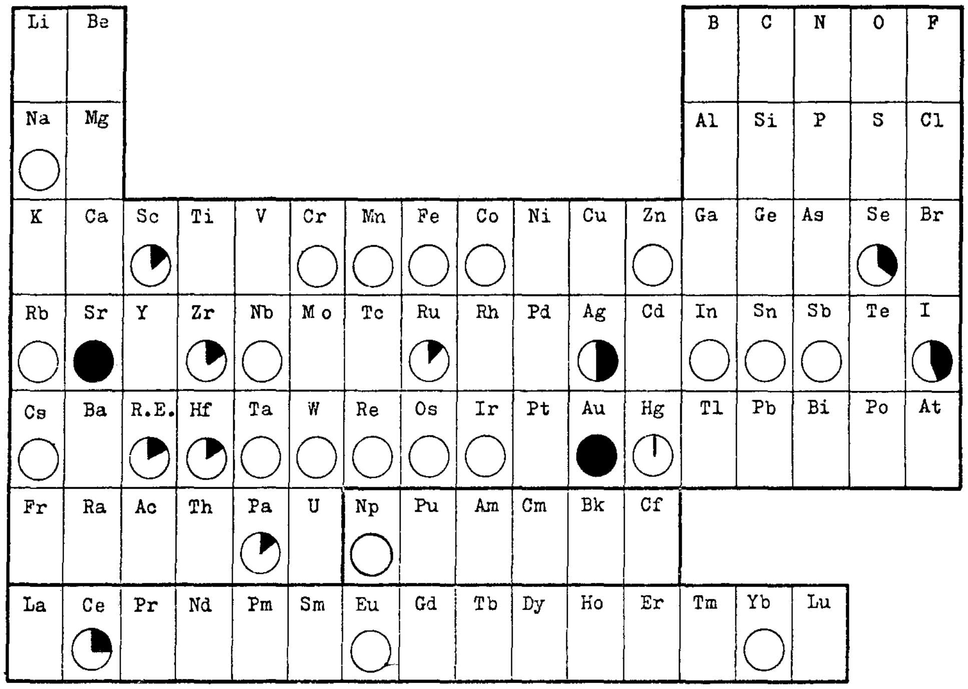
3.16.3 Applications

LDF does not seem particularly interesting. No application was done.

LEAD FLUORIDE

63(LDF/1S)

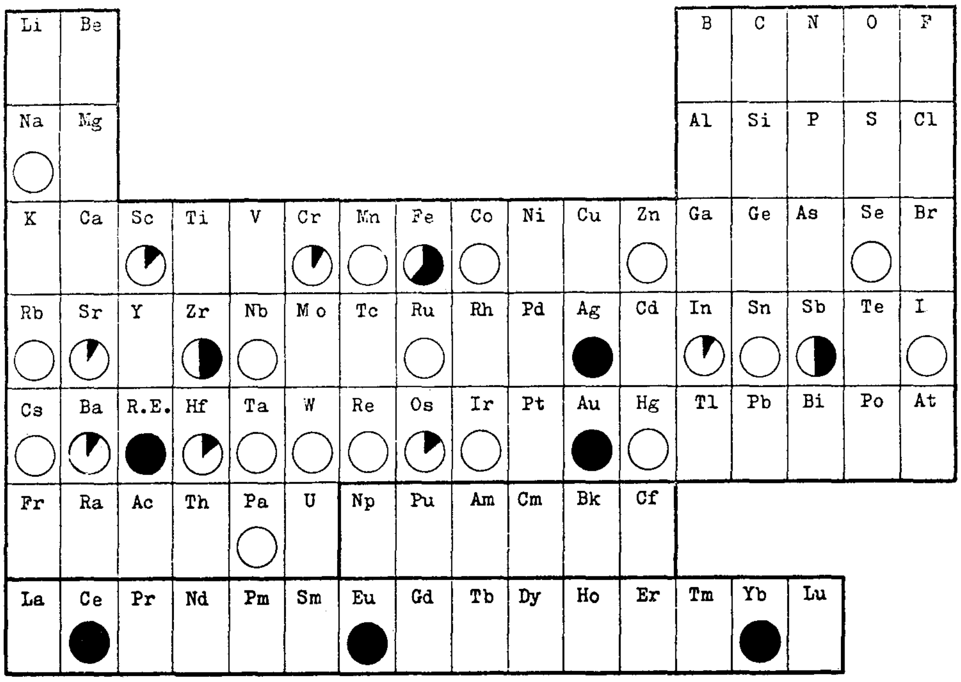
1 M H_2SO_4



LEAD FLUORIDE

64(LDF/6F)

6 M HF



3.17 Cerous oxalate (COX)

3.17.1 Material

Technical grade cerous oxalate (B.D.H., United Kingdom), was used.

3.17.2 Tracer experiments

Carried out in the following media:

a) 1 M H_2SO_4 (37 ions): table 65 (COX/1S)

b) 6 M HF (39 ions): table 66 (COX/6F)

3.17.3 Applications

The following applications were done:

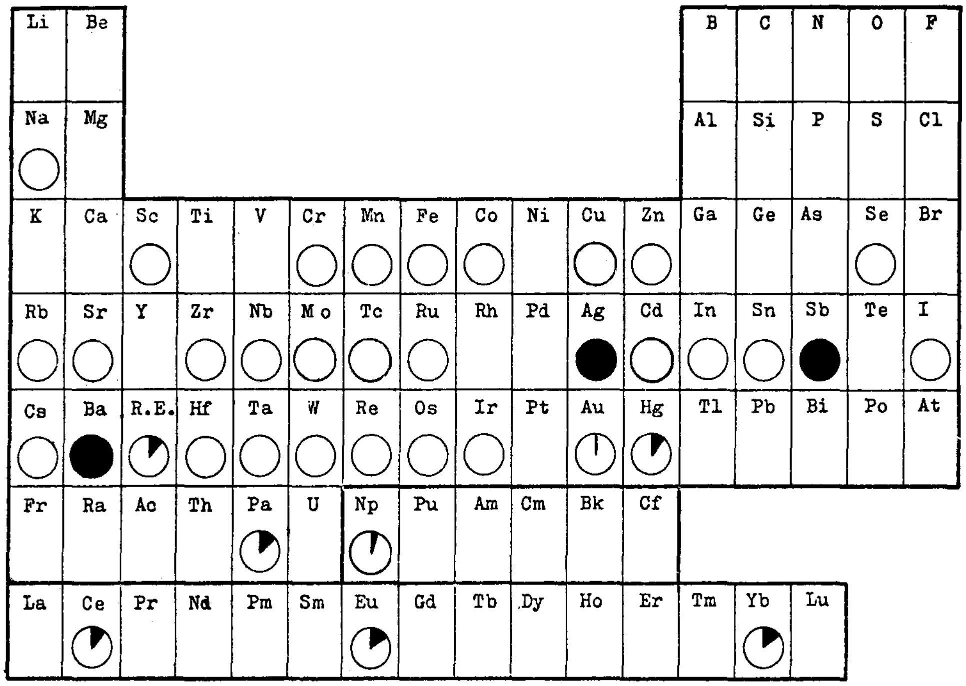
a) Determination of Cu and Zn in leaf tissues.
The sample in 6 M HF, was passed on columns of COX and HAP in series. The first retains ^{24}Na and ^{56}Mn, the second retains ^{42}K. ^{64}Cu and ^{69m}Zn are determined in the eluate.

b) Determination of Co and Cs in soils (see 3.2.3).

CEROUS OXALATE

65(COX/1S)

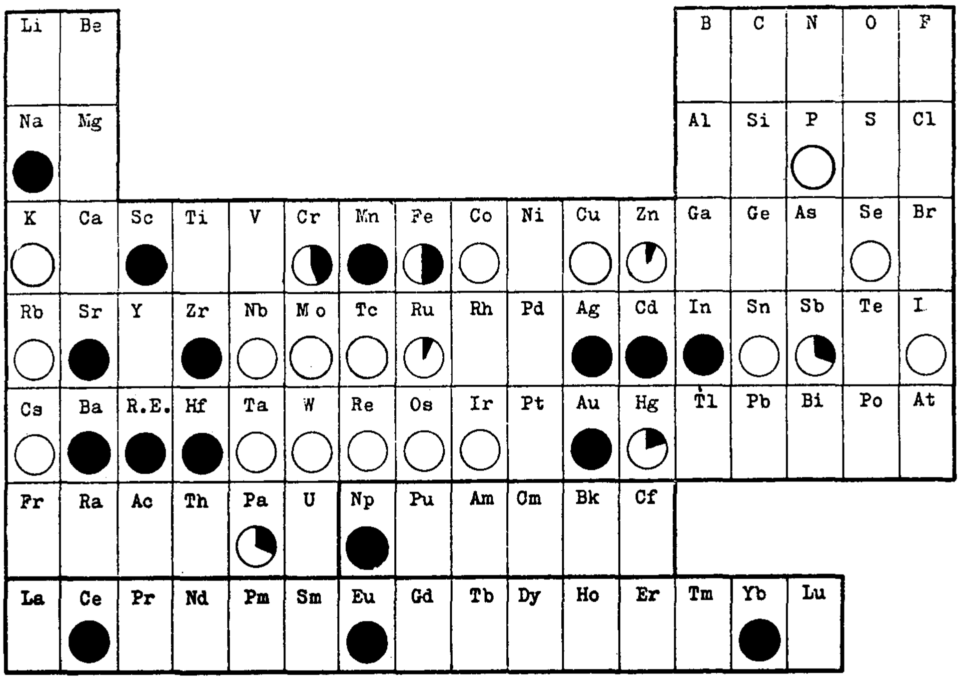
1 M H_2SO_4



CEROUS OXALATE

66(COX/6F)

6 M HF



3.18 Anion exchange Resin (AER)

3.18.1 Material

Dowex 1 x 8 100-200 Mesh (BioRad, USA) was used. Preliminary conditioning was done with 15 ml of eluent.

3.18.2 Tracer experiments

Carried out in the following media:

a) 6 M HCl (33 ions): table 67 (AER/6Cl)

b) 6 M $HClO_4$ (32 ions): table 68 (AER/6P)

c) 6 M HF (33 ions): table 69 (AER/6F)

d) 7 M HNO_3 (32 ions): table 70 (AER/7N)

3.18.3 Applications

Anion exchange resins are at the base of many reported separation schemes. They couple very well with inorganic exchangers as their behaviour is often different. They afford therefore a means for removing elements which are not affected by most inorganic exchangers tested in the present work, such as Zn.

No application in connection with inorganic exchangers was yet done by us.

ANION EXCHANGE RESIN

6 M HCl

67(AER/6Cl)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ●	Co ○	Ni	Cu	Zn ●	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ◔	Nb ◔	Mo	Tc	Ru ◔	Rh	Pd	Ag ○	Cd	In ◔	Sn ●	Sb ●	Te	I ●
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ◕	W ●	Re ●	Os ●	Ir ○	Pt	Au ●	Hg ●	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ◕	U	Np ○	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

ANION EXCHANGE RESIN

6 M $HClO_4$

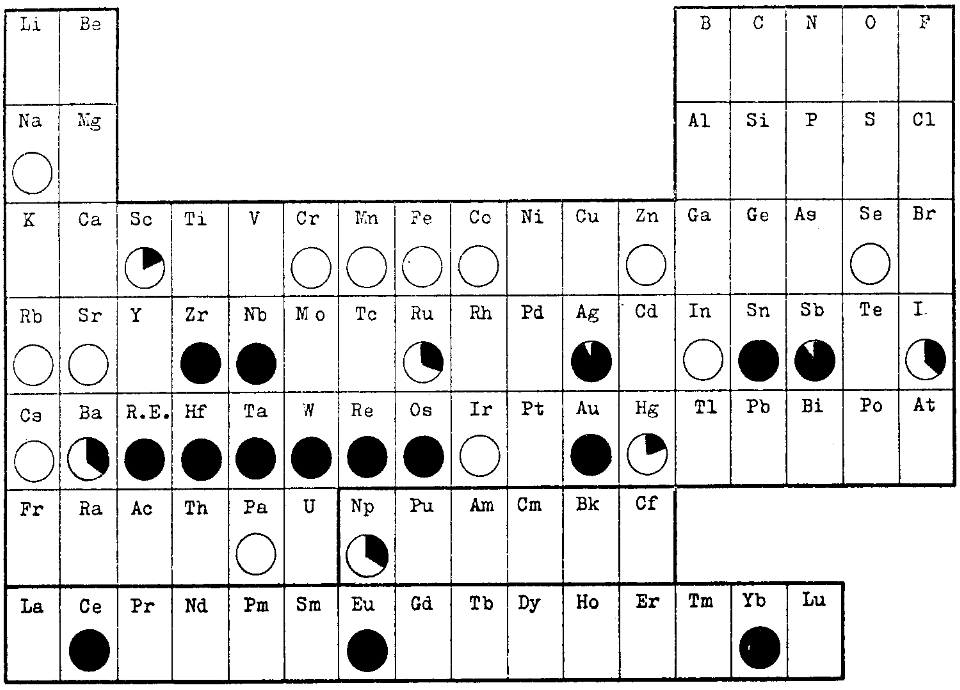
68(AER/6P)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ◔	Cd	In ○	Sn ○	Sb ●	Te	I ◔
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ◔	W ●	Re ○	Os ○	Ir ○	Pt	Au ◕	Hg. ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

ANION EXCHANGE RESIN

6 M HF

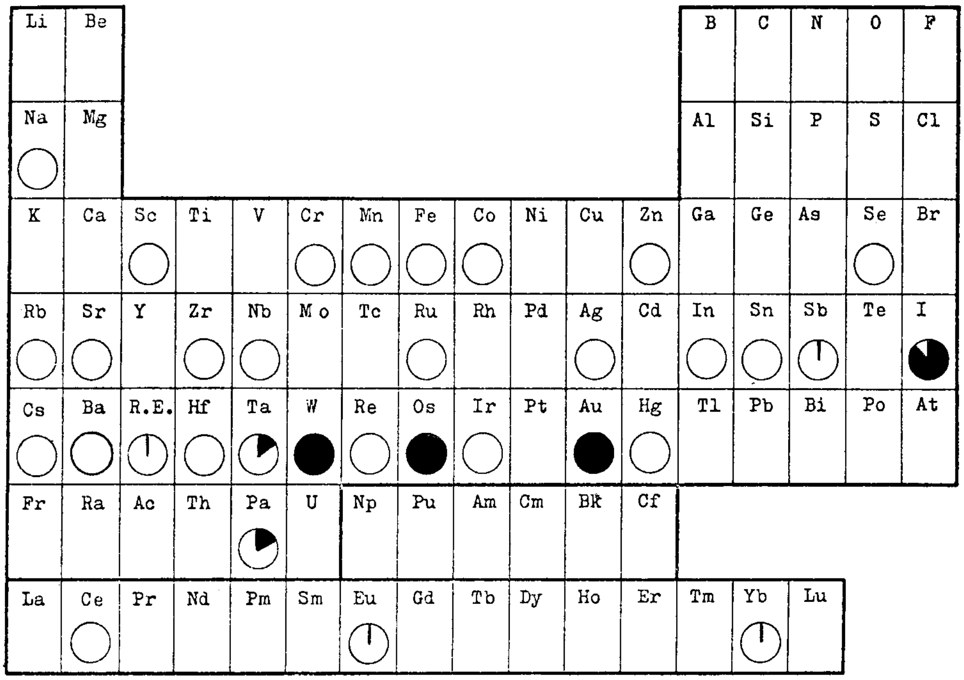
69(AER/6F)



ANION EXCHANGE RESIN

7 M HNO_3

70(AER/7N)



3.19 Cation Exchange Resin (CER)

3.19.1 Material

Dowex 50 x 8, 100-200 mesh (BioRad, USA) was used. Preliminary conditioning was done with 15 ml of eluent.

3.19.2 Tracer experiments

Carried out in the following media:

a) 6 M HCl (32 ions): table 71 (CER/6Cl)

b) 6 M $HClO_4$ (33 ions): table 72 (CER/6P)

c) 6 M HF (33 ions): table 73 (CER/6F)

d) 7 M HNO_3 (32 ions): table 74 (CER/7N)

3.19.3 Applications

The behaviour of cation exchangers in the experiments done is less interesting than that of the anion exchangers.

No application in connection with inorganic exchangers was yet done by us.

CATION EXCHANGE RESIN

6 M HCl

71(CER/6Cl)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ○	Ti	V	Cr ○	Mn ○	Fe ○	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ○	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd	In ○	Sn ○	Sb ◕	Te	I ◔
Cs ○	Ba ○	R.E. ○	Hf ○	Ta ○	W ●	Re ○	Os ○	Ir ○	Pt	Au ◔	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ○	U	Np	Pu	Am	Cm	Bk	Cf					
La	Ce ○	Pr	Nd	Pm	Sm	Eu ○	Gd	Tb	Dy	Ho	Er	Tm	Yb ○	Lu		

CATION EXCHANGE RESIN

6 M $HClO_4$

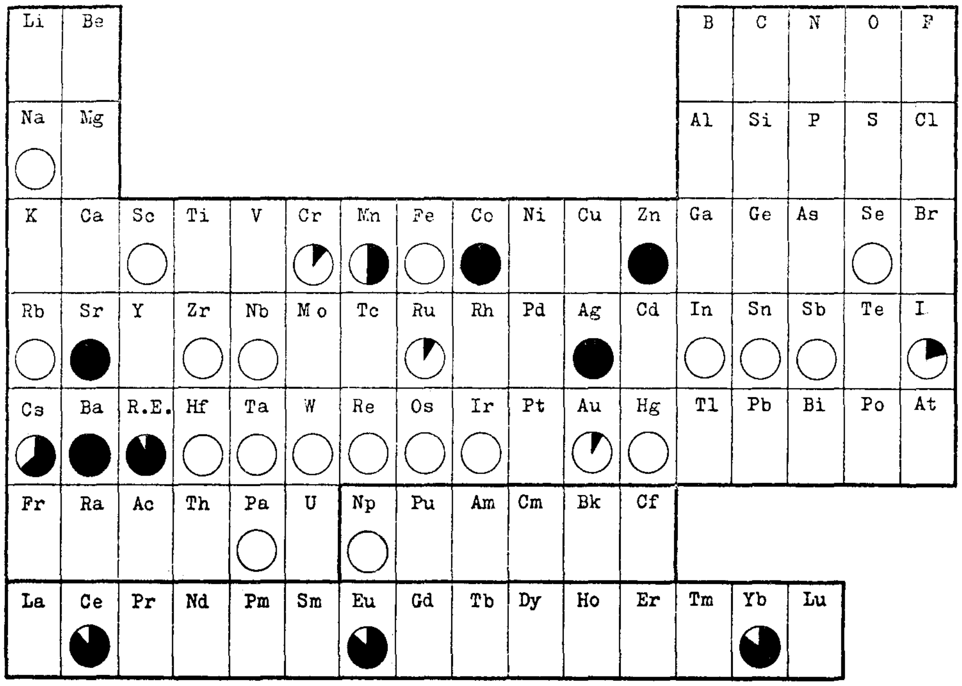
72(CER/6P)

Li	Be											B	C	N	O	F
Na ○	Mg											Al	Si	P	S	Cl
K	Ca	Sc ●	Ti	V	Cr ○	Mn ○	Fe ◔	Co ○	Ni	Cu	Zn ○	Ga	Ge	As	Se ○	Br
Rb ○	Sr ○	Y	Zr ◔	Nb ○	Mo	Tc	Ru ○	Rh	Pd	Ag ○	Cd	In ○	Sn ○	Sb ○	Te	I ◕
Cs ○	Ba ○	R.E. ◕	Hf ○	Ta ●	W ◔	Re ○	Os ○	Ir ◔	Pt	Au ◔	Hg ○	Tl	Pb	Bi	Po	At
Fr	Ra	Ac	Th	Pa ●	U	Np ◔	Pu	Am	Cm	Bk	Cf					
La	Ce ◕	Pr	Nd	Pm	Sm	Eu ◕	Gd	Tb	Dy	Ho	Er	Tm	Yb ◕	Lu		

CATION EXCHANGE RESIN

6 M HF

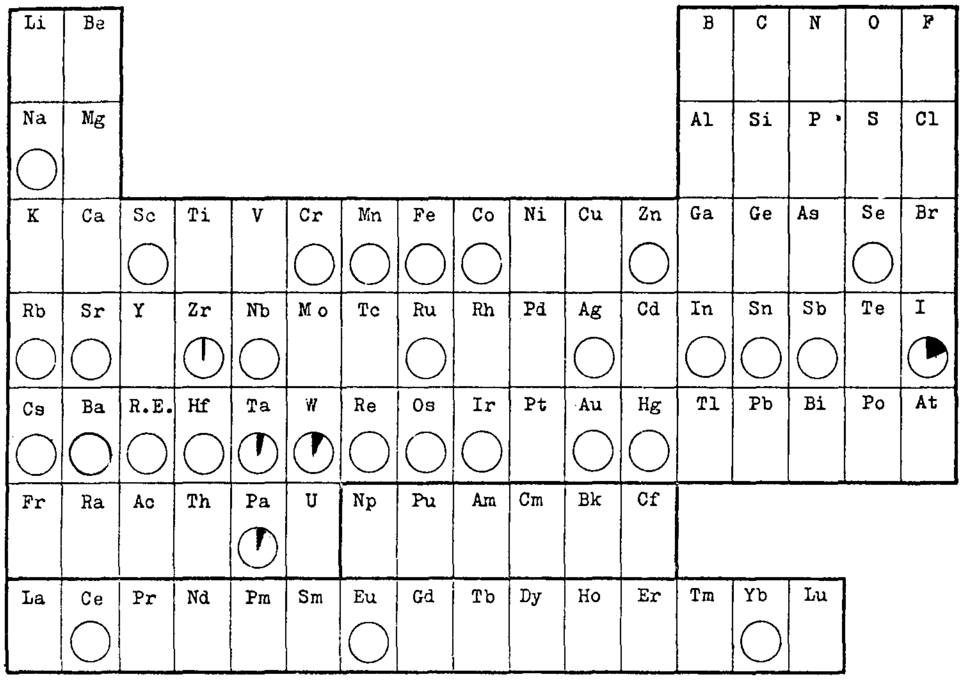
73(CER/6F)



CATION EXCHANGE RESIN

7 M HNO_3

74(CER/7N)



4. AKNOWLEDGMENTS

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TABLE I - Manufactures of ionic precipitates used in this work.

	Ionic precipitate
Soc. Carlo Erba Via Imbonati, 24 - MILANO - Italy	HMD, AMD, SDO, HAP, CDO, TDO
B.D.H. International Ltd Poole, Dorset, United Kingdom	CUS, CUC, CDS, LDF, COX
BioRad Laboratories 32nd and Griffin Ave, RICHMOND, California, U.S.A.	ZPH, AER, CER
Applied Research s.p.r.l. 29 Rue Herkaliers, BRUXELLES 8, Belgium	PAA, ZPH
M.Woelm Post Office Box 840, Eschwege, Wester Germany	AAO
S.E.R.A.I. 1091 Chaussée d'Alsemberg, BRUXELLES, 18, Belgium	TPH, SPH

TABLE II. Radiotracer used and carrier concentrations.

RADIOTRACER	CONCENTRATION ug/cc	RADIOTRACER	CONCENTRATION ug/cc
F-18 (-I)	0.02	Ag-110m (I)	0.02
Na-22 (I)	0.02	Cd-115 (II)	5
Al-28 (III)	1	In-114m (III)	0.06
Mo-27 (II)	1	Sn-117m (*)	10-40
P-32 (V)	0.02	Sb-124 (*)	0.05
S-35 (VI)	0.02	Te-131 (IV)	15
Cl-38 (-I)	0.4	I-131 (-I)	0.1
K-42 (I)	10	Cs-134 (I)	0.02
Ca-47 (II)	400	Ba-131 (II)	30-100
Sc-46 (III)	0.02	La-140 (III)	0.02
Ti-51 (IV)	1	Ce-141 (III)	0.2
V-52 (*)	0.005	Nd-147 (III)	0.1-0.5
Cr-51 (III)	0.2	Pm-151 (III)	carrier free
Mn-54 (II)	0.02	Eu-152;Eu154 (III)	0.02
Fe-59 (III)	20	Tb-160 (III)	0.01
Co-60 (II)	0.05	Yb-169 (III)	0.01
Ni-65 (II)	20	Lu-177 (III)	0.002-0.01
Cu-64 (II)	0.8	Hf-181 (IV)	0.01
Zn-65 (II)	2	Ta-182 (V)	0.01
Ga-72 (III)	0.2	W-185 (VI)	2
Ge-77 (IV)	20	Re-186 (VII)	0.1-1
As-76 (*)	0.2	Os-191 (IV)	0.05-0.1
Se-75 (IV)	0.2	Ir-192 (III)	0.001
Br-82 (-I)	0.05	Pt-199 (IV)	2-3
Rb-86 (I)	1	Au-198 (III)	0.02-0.1
Sr-85 (II)	10	Hg-203 (II)	0.05
Y-90 (III)	0.05	Th-233 (IV)	0.1
Zr-95 (IV)	1-10	Pa-233 (V)	carrier free
Nb-95 (V)	0.02	U-239 (VI)	0.02-0.1
Mo-99 (VI)	0.2	Np-139 (IV)	carrier free
Tc-99m(VII)	carrier free		
Ru-103(IV)	0.1		
Pd-103(II)	1		

(*) Uncertain oxidation state.

TABLE III. Summary of experiments done and keys of the code used in indexing the tables. The figures are the number of ion, whose behaviour was tested for the particular couple material/medium.

MEDIUM →		0.1M HNO_3 60°C	0.1M HNO_3	1M HCl	1M HNO_3	1M HNO_3 90°C	1M $HClO_4$	1M $HClO_4$ 90°C	1M H_2SO_4	6M HCl	6M HCl	6M HF	7M HNO_3	7M HNO_3 90°C	10M HCl	12M HCl	14M HNO_3	TOTAL
CODE →		0.1N 60°C	0.1N	1Cl	1N	1N 90°C	1P	1P 90°C	1S	6Cl	6P	6F	7N	7N 90°C	10Cl	12Cl	14N	
MATERIAL	CODE																	
Hydrated Manganese Dioxide	HMD	61			50		51					52					51	265
Anhydrous Manganese Dioxide	AMD						50					50					51	151
Silicon Dioxide	SDO						49						49					98
Hydrated Antimony Pentoxide	HAP				36		51			58	36	53	32			60	53	379
Polyantimonic Acid	PAA									33			32				32	97
Antimony Tetroxide	ATO				36						36	36	36		36		36	216
Cadmium Oxide	CDO		59															59
Acid Aluminium Oxide	AAO					42	50	46					48	42				228
Tin Dioxide	TDO	41		57	59		47					46	56				46	352
Titanium Phosphate	TPH								34	38	38		41					151
Zirconium Phosphate (Bio Rad)	ZPH								35	33	33		36					137
Zirconium Phosphate (Appl.Res.)										33	34		34					101
Stannic Phosphate	SPH								33		33		34					100
Cupric Sulphide	CUS								33	34	34		34					135
Cuprous Chloride	CUC								34		36	36						106
Cadmium Sulphide	CDS											35						35
Lead Fluoride	LDF								32			32						64
Cerous Oxalate	COX								37			39						76
Anion Exchange Resin	AER									33	32	33	32					130
Cation Exchange Rerisin	CER									32	33	33	32					130
TOTAL		102	59	57	181	42	298	46	238	294	345	445	496	42	36	60	269	3010

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>
> Alfred Nobel

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