Determination of Difficult-to-Measure Nuclides in Radioactive Wastes of NPP Paks, Hungary

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Determination of actinides and ^{93}Zr in NPP wastes with combined methods based on the use of
UTEVA,
TRU,
DGA

Determination of DTM fission products: ^{90}Sr,
^{135}Cs

Determination of DTM activation products: ^{55}Fe-^{59}Ni-^{63}Ni
^{93m}Nb-^{94}Nb-^{125}Sb

Brief overview on the determination of DTM nuclides at INR-ISOTOPTECH Co.

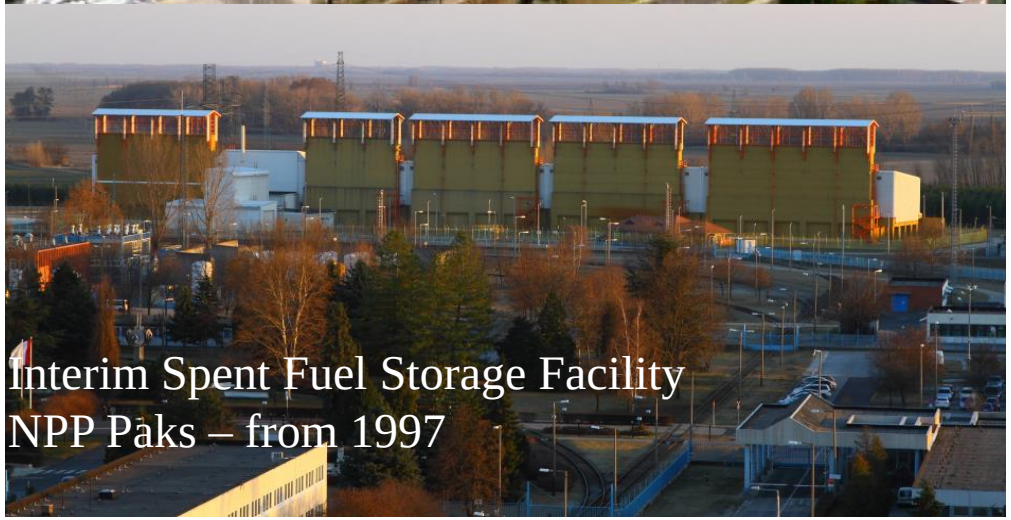
^{3}H, ^{14}C, ^{36}Cl, ^{129}I, ^{99}Tc, ^{108m}Ag, ^{107}Pd, ^{79}Se

Scaling factors

Nuclear facilities in Hungary

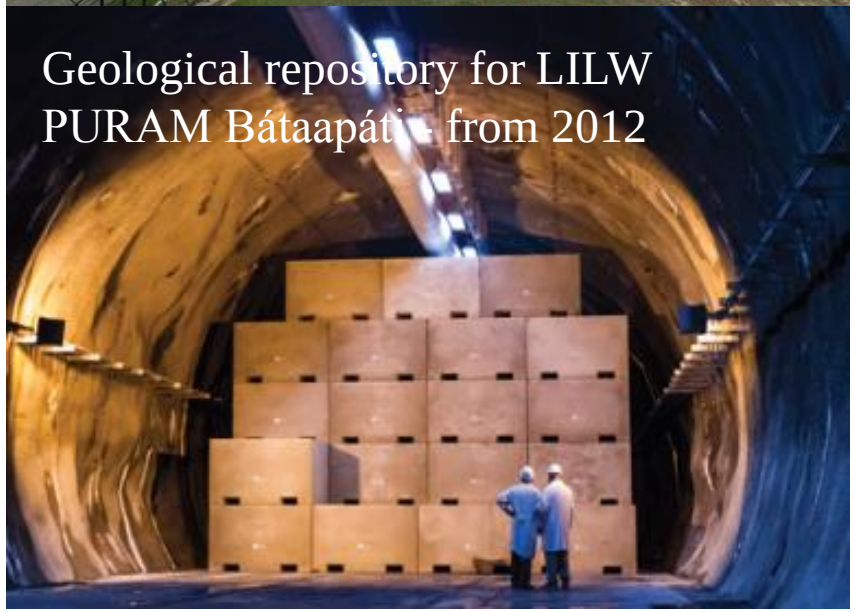
From
1982

VVER 440/V 213 pressurised water reactors



Interim Spent Fuel Storage Facility
NPP Paks – from 1997

Near surface repository for
institutional LILW
PURAM Püspökszilágy



Geological repository for LILW
PURAM Bátaapáti - from 2012

Waste processing and characterization at NPP Paks

Solid wastes:
collection, comprassion, storage in drums (210 L), 707 drums in 2014
Characterization by Segmented Gamma Scanning (SGS) of drums and SF method

Liquid radioactive wastes:
radioactivity originates from the PC
collected and processed by evaporation

- **evaporator concentrates**: stored in tanks of 200 m3
  ~400 g/L salt content (borate), pH ~13 (NaOH),
  oxalic acid, citric acid, EDTA
  LILW
  ~6500 m^3 by 2014

  liquid waste treatment technology (LWT):
  destruction of organics with KMnO4, removal of Co by filtration of hydroxide ppt,
  ultrafiltration, Cs removal with CsTREAT (FORTUM) ion exchanger, borax removal
  solidification by cementization, storage in drums, burial at Waste Depository Bátaapáti + clearence
  wastes of different composition
- **decontamination solutions:** AP-CITROX technology
- **spent resins**

Characterization by γ scanning, isotope specific analysis → SF calculation

Nuclides to be analyzed

Institute for Nuclear Research, HAS - ISOTOPTECH Co.				
Nuclide	$T_{1/2}$ (year	MDA [Bq/l]	Type of measurement	Remark
Activation products				
^{3}H	12,32	1	beta spectrometry	DTM
^{14}C	5730	1	beta spectrometry	DTM
^{36}Cl	301000	10	beta spectrometry	DTM
^{41}Ca	102000	10	AMS	DTM
Fission products				
^{129}I	15700000	0,1	beta spectrometry	DTM
^{99}Tc	211000	0,1	beta spectrometry	DTM
^{106}Ru	1,01	NR	gamma spectrometry	
^{107}Pd	6500000	1	beta spectrometry	DTM
^{79}Se	327000	10	ICP-MS	DTM
^{134}Cs	2,06	NR	gamma spectrometry	
^{137}Cs	30,07	10	gamma spectrometry	KN
^{144}Ce	0,78	NR	gamma spectrometry	
^{154}Eu	8,8	NR	gamma spectrometry	
Activated corrosion products				
^{54}Mn	0,85	NR	gamma spectrometry	
^{60}Co	5,27	10	gamma spectrometry	KN
^{108m}Ag	418	1	gamma spectrometry	DTM
^{110m}Ag	0,68	NR	gamma spectrometry	

KN	Key Nuclide
DTM	Difficult-to-Measure Nuclide

RADANAL Ltd.				
Nuclide	$T_{1/2}$ (year	MDA [Bq/l]	Type of measurement	Remark
Fission products				
^{90}Sr	29,1	1	beta spectrometry	DTM
^{135}Cs	2300000	1	NAA	DTM
			ICP-MS	
^{125}Sb	2,76	NR	gamma spectrometry	DTM
Activated corrosion products				
^{55}Fe	2,73	1	X-ray spectrometry	DTM
^{59}Ni	75000	1	X-ray spectrometry	DTM
^{63}Ni	100	10	beta spectrometry	DTM
^{93}Zr	1500000	1	ICP-MS	DTM
^{93m}Nb	16,1	10	X-ray spectrometry	DTM
^{94}Nb	20300	1	gamma spectrometry	DTM
Actinides				
^{234}U	244000	0,05	alpha spectrometry	DTM
^{235}U	704000000	0,05	alpha spectrometry	DTM
^{237}Np	2100000	0,05	ICP-MS	DTM
^{238}U	4470000000	0,05	alpha spectrometry	DTM
^{238}Pu	86,4	0,05	alpha spectrometry	DTM
^{239}Pu	24400	0,05	alpha spectrometry	DTM
^{240}Pu	6540	0,05	alpha spectrometry	DTM
^{241}Am	432	0,05	alpha spectrometry	DTM
^{243}Am	7380	0,05	alpha spectrometry	DTM
^{242}Cm	0,45	0,05	alpha spectrometry	DTM
^{244}Cm	17,9	0,05	alpha spectrometry	DTM

Determination of DTM nuclides at RADANAL Ltd.

Determination of actinides and ^{93}Zr

Goal was to develop a combined procedure for the selective separation of Pu, Am-Cm, Np, U, Th (Zr) using a **single chromatographic column.**

The procedure should be

- adequate for analysis of liquid NPP waste (accurate, sensitive for LLW)
- adequate for measurement by α spectrometry and/or ICP-MS
- simple, cheap, fast for use in emergency situation.

Resin of high selectivity for actinides is needed.

3 methods have been developed:

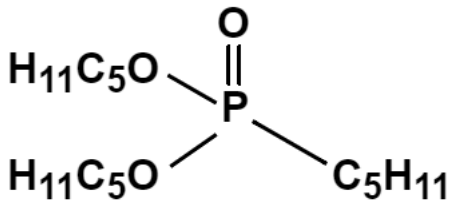
UTEVA procedure

TRU procedure

DGA procedure

UTEVA® procedure
Chromatographic procedure for actinides (U, Th, Pu, Np)

Pu(IV) or Pu(VI)
U(VI)
Th(IV)
Np(VI)



DP[PP]

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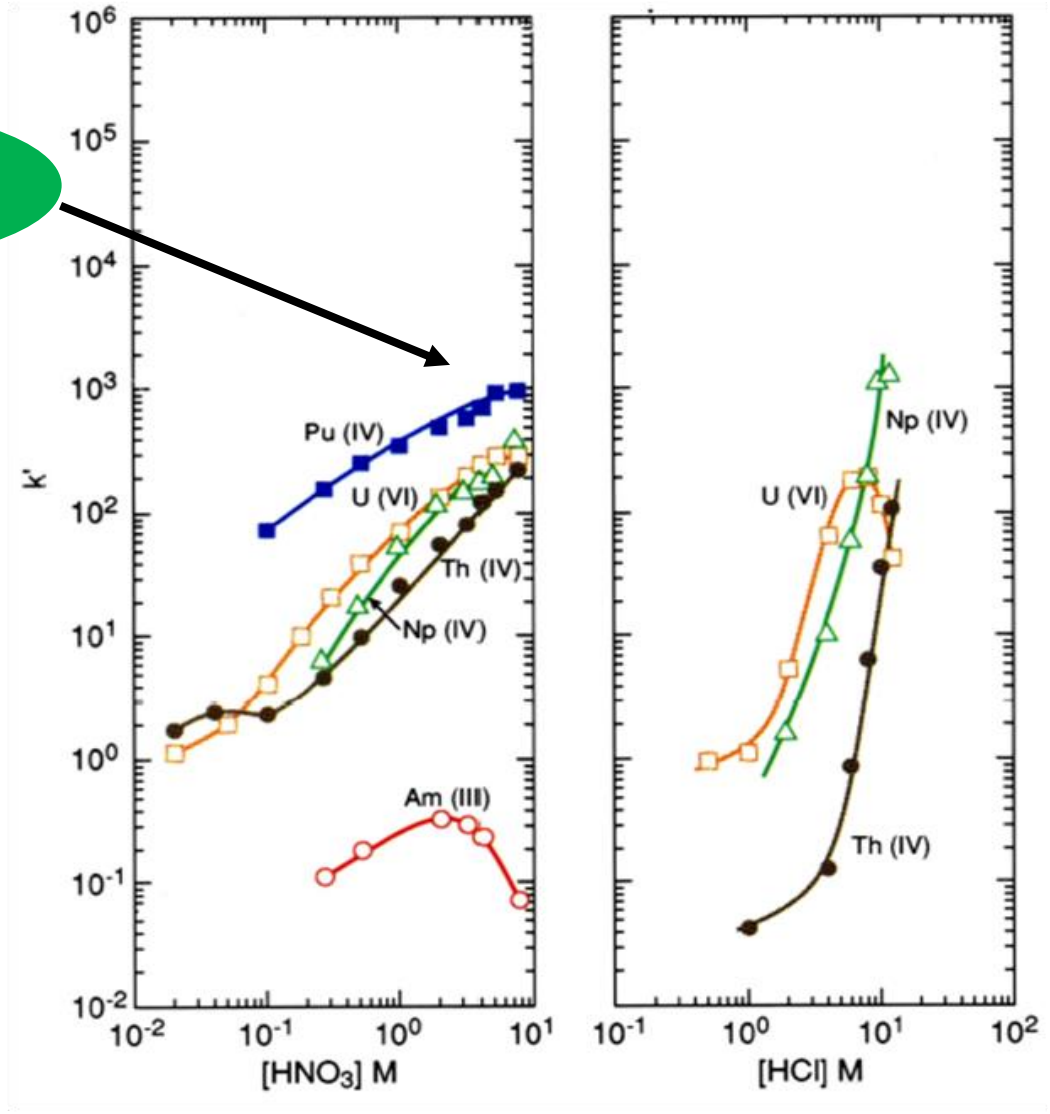
Horwitz et al.

N. Vajda, Zs. Molnár, E. Kabai, Sz. Osvath: Simultaneous Determination of Long-Lived Radionuclides in Environmental Samples, 9th Int. Symposium on Environmental Radiochemical Analysis, Maidstone, U.K., 18-20 Sept. **2002**, (In: Peter Warwick (ed.): Environmental Radiochemical Analysis II; The Royal Society of Chemistry, Cambridge, 2003; pp. 185-196.)

High k' for Ac(IV, VI) not for Am



UTEVA procedure: Basic concept of separation

- **Load**:

  U(VI), Th(IV), Np(VI), Pu(VI) – $K_2S_2O_8$ or

  U(VI), Th(IV), Pu(IV) –$NaNO_2$

  retention of actinides from 8M HNO_3/0.5M $Fe(NO_3)_3$:

- **Elution of Pu(III)** with 9M HCl/NH_4I

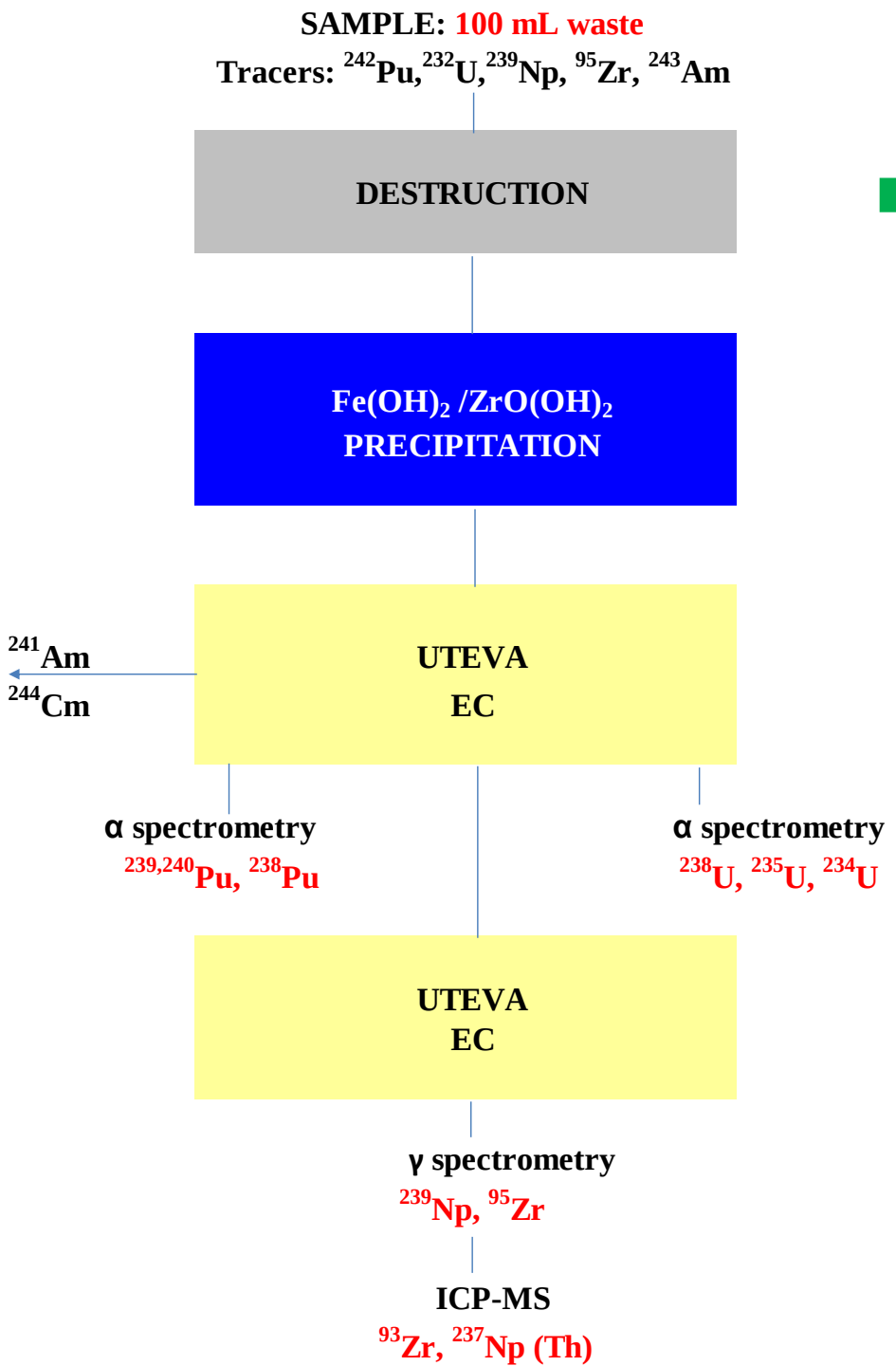
  Reduction of Pu to Pu(III)
- **Elution of Th, Np** with 4M HCl
- **Elution of U** with 0.1M HCl.

Ac(VI) and Ac(IV) after oxidation state adjustment

Fe(III) nitrate is used as salting-out agent

On-column reduction to Pu(III), Np(IV)

Ac(III) are not retained!



Determination of U, Pu (Np, Zr) in NPP wastes
Flowchart of the UTEVA procedure

Acid destruction

Preconcentration is necessary

Oxidation state adjustment is recommended:
$K_2S_2O_7$ with Ag+ catalyst to form Np(VI), Pu(VI)

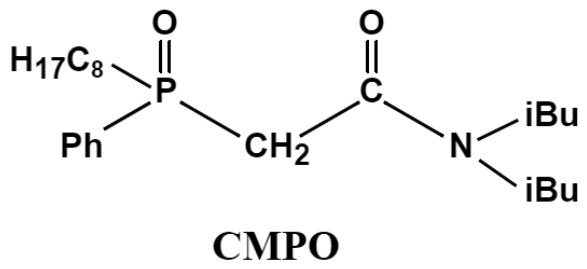
Load from 8M HNO_3 with $Fe(NO_3)_3$ as salting-out agent

Optional: Np, Zr determination
Np-Zr purification with UTEVA from 9M HCl load

Optional: Am determination from the 1st UTEVA effluent:
Preconcentration with Ca oxalate
Am separation with TRU resin

TRU® procedure
Chromatographic procedure for all actinides (Ac) in small samples

Pu **Am**
Np
Th
U



CMPO

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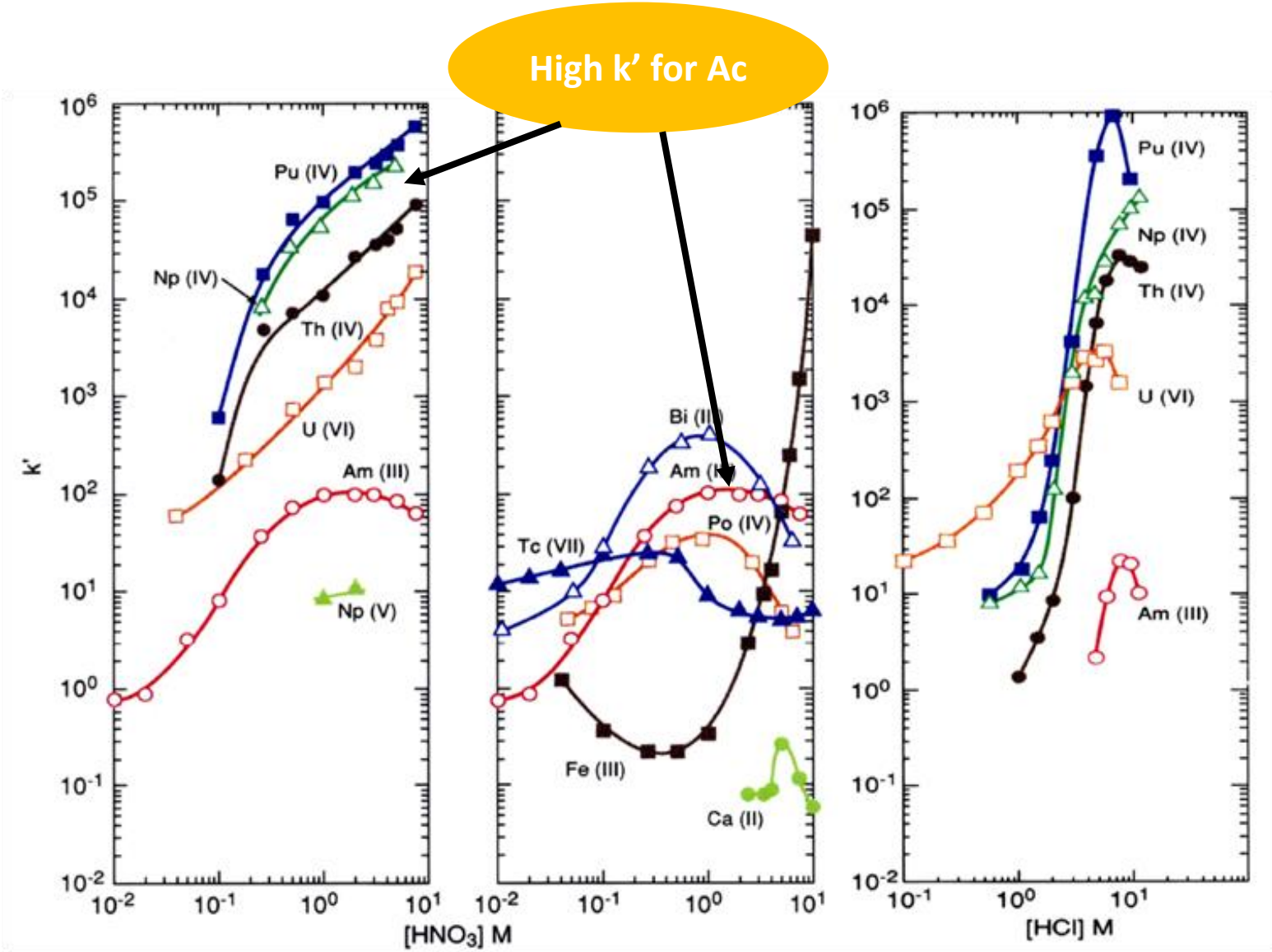
N. Vajda, A. Törvényi, G. Kis-Benedek, C.K. Kim, B. Bene, Zs. Macsik: Rapid method for the determination of actinides in soil and sediment samples by alpha spectrometry. Radiochimica Acta **2009**, 97, 395-401



TRU procedure: Basic concept of the separation

- **Load**: retention of all actinides from 2M HNO_3

  Pu(IV), Am(III), U(VI), Th(IV), Np(IV),
- **Elution of Am** with 4M HCl.
- **Elution of Pu(III)** with 4M HCl /Ti^{3+}

  while

  Np is reduced to Np(IV) - retained,

  Th and U(IV) are retained
- **Elution of Th** with 2M HCl/Ti^{4+}
- **Elution of Np** with 2M HCl/Ti^{3+}

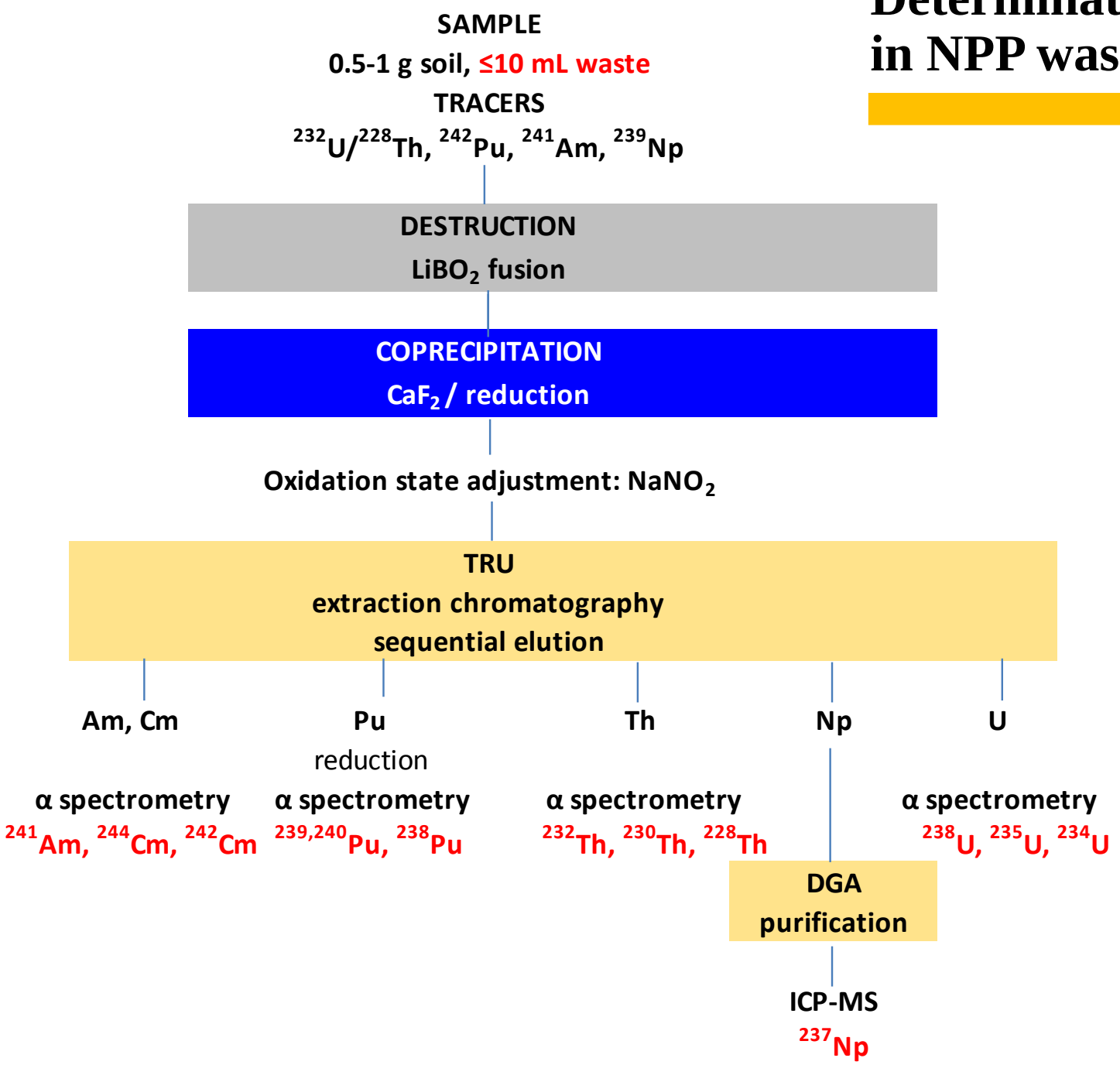
  while U is retained,
- **Elution of U** with 0.1M HCl.

Ac(III), Ac(IV), Ac(VI) are retained

On-column redox reactions are feasible!

Small load otherwise Am leakage

Determination of Pu, Am, Cm, U (Np) isotopes in NPP wastes – flowchart of TRU procedure



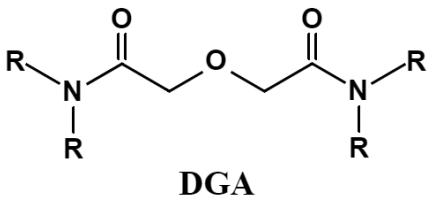
Rapid method for Am and Pu
due to fusion
Optional: destruction with mineral acids

Coprecipitation is necessary
Removal of matrix

Optional
analysis of **Pu, Th, Np, U isotopes**
after purification with DGA resin columns
to remove Ti species
using other tracers
by ICP-MS

DGA® procedure
Chromatographic procedure for all actinides (Ac)

Pu
Am
U
Th
Np



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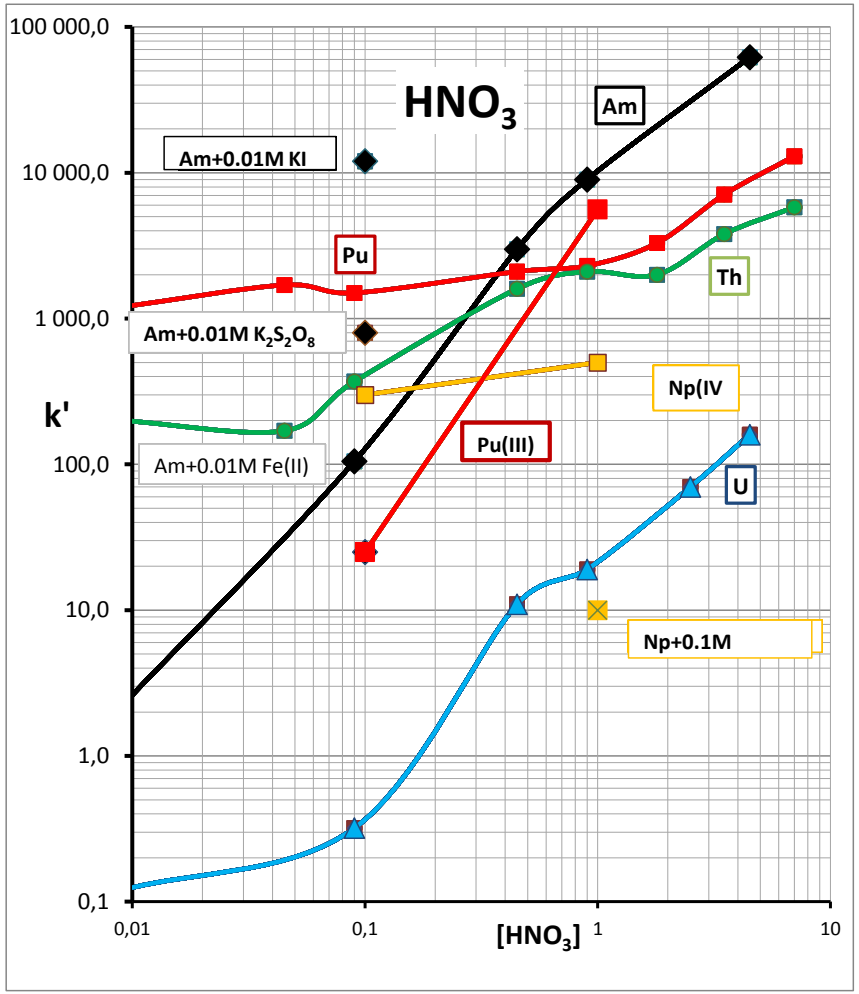
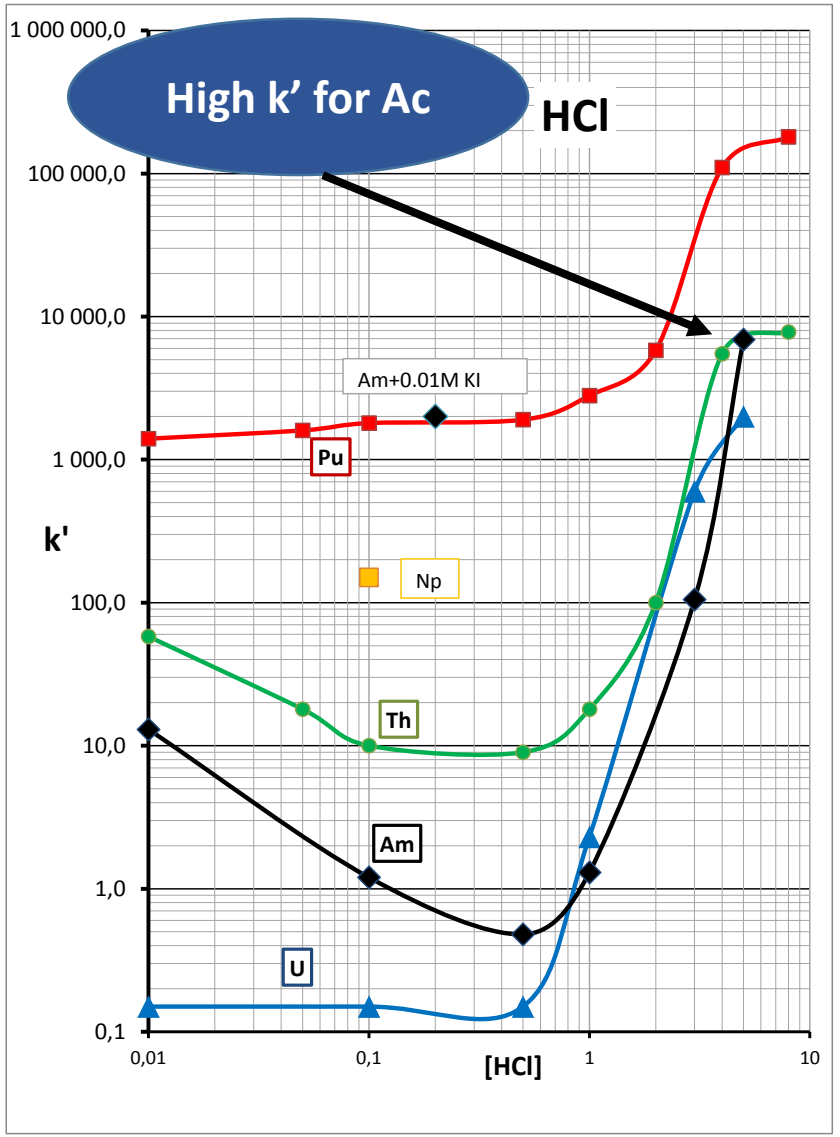
Horwitz et al.

Groska J, Vajda N, Molnar Z, Bokori E, Szeredy P, Zagyvai M (**2016**) Determination of actinides in radioactive waste after separation on a single DGA resin **column, JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY 309: (3) pp. 1145-1158.**





DGA procedure: Basic concept of the separation

- **Load**: retention of all actinides in reduced forms from 4M HCl/ Na_2SO_3
  U(IV), Th(IV), Np(IV), Pu(III), Am(III)

- **Elution of U** with dilute HNO_3 after oxidation to U(VI), while
  Pu and Np are oxidized to Pu(IV), Np(IV)/Np(VI) - retained,
- Reduction of Pu and Np to Pu(III) and Np(IV),

- **Elution of Th, Np** with complexing agent oxalic acid, while
  trivalent actinides (Pu(III), Am) are retained,

- **Elution of Pu** with oxalic acid after oxidation to Pu(IV)

- **Elution of Am** with dilute HCl.

Ac(III) and Ac(IV) are completely retained!

On-column redox reactions are feasible!

Only Ac(IV) form oxalate complexes !

Optimization of the DGA procedure

Studied by **model experiments**

with single tracers

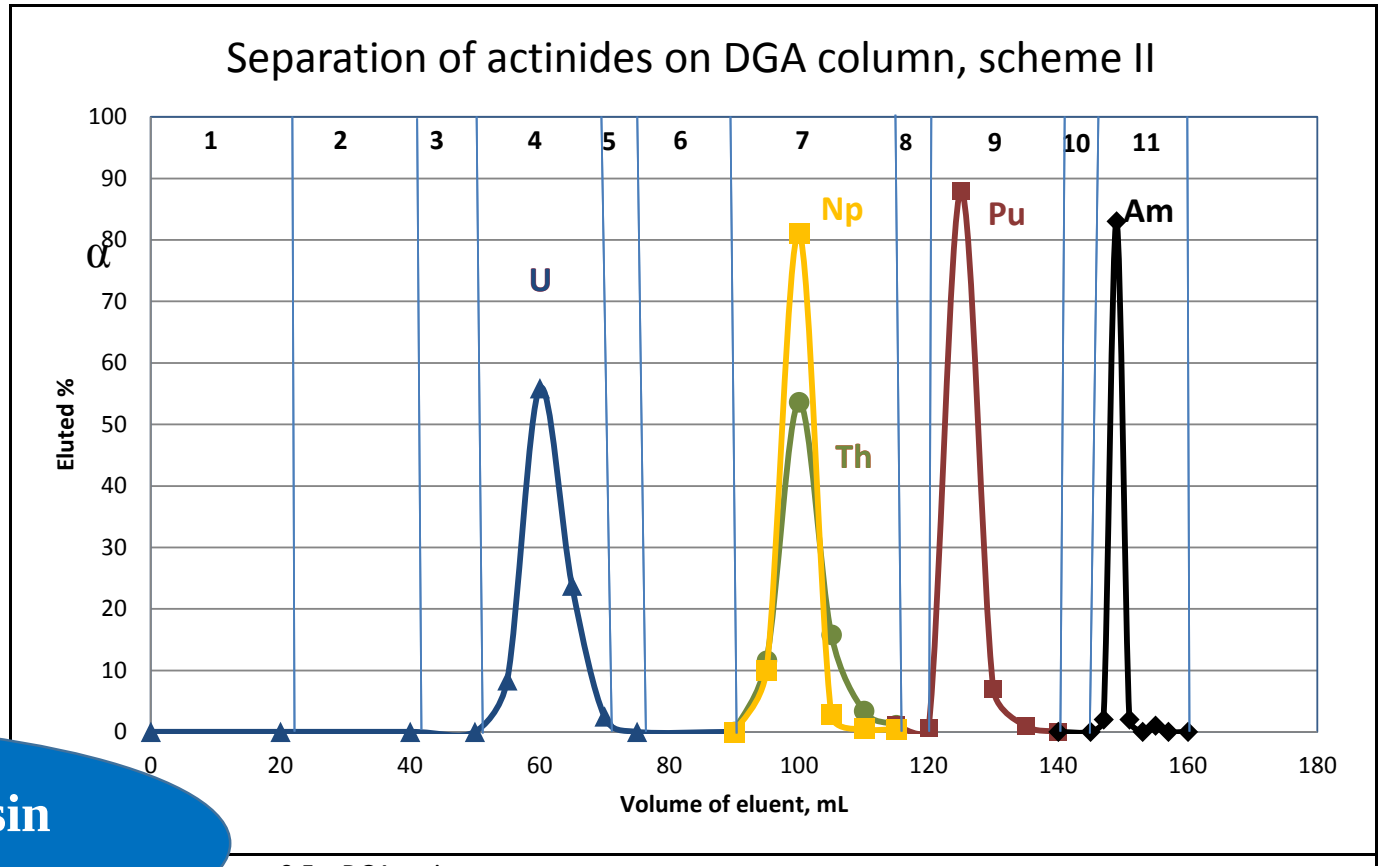
^{233}U, ^{230}Th, ^{239}Pu, ^{241}Am

^{239}Np produced from $^{238}U(n,\gamma)$

measured by LSC or γ spectrometry

Recoveries

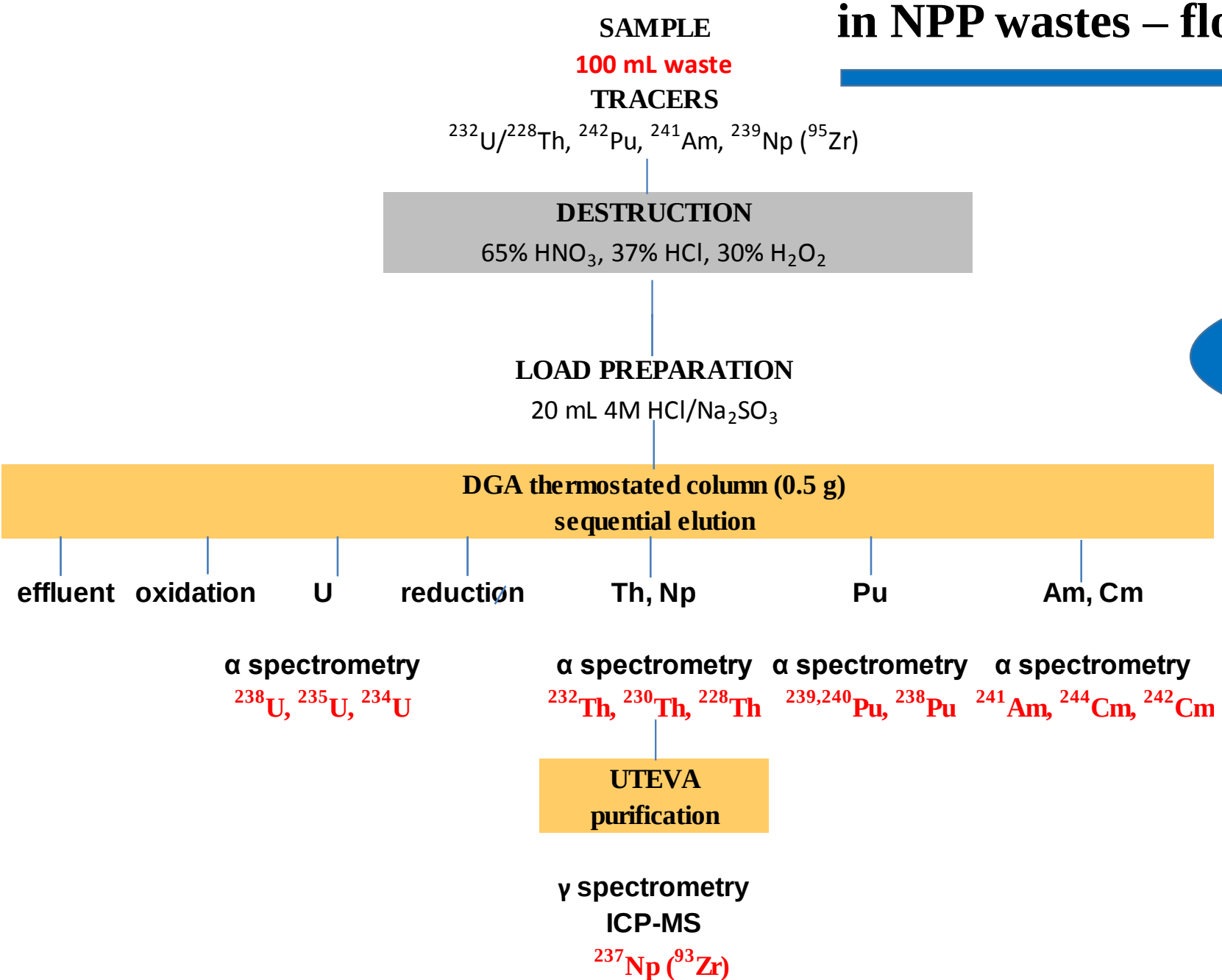
U	Th	Np	Pu	Am
90%	86%	95%	96%	88%



- U, Pu, Am fractions are well separated
- Np and Th are collected together
- Between the strip solutions wash solutions
- Recoveries are high (> 86%)
- Contamination by other actinides is ≤1-2%

Major advantage:
Use of a single small resin column for all Ac in big samples!

Determination of U, Pu, Np, Am, Cm, Zr isotopes in NPP wastes – flowchart of DGA pocedure



Big volumes are treated.

Conventional destruction.

Preconcentration of Ac and Zr is skipped!

Purification of Np from U is necessary.

Determination of ^{237}Np and ^{93}Zr in NPP wastes

UTEVA procedure:

DESTRUCTION
CO-PRECIPITATION
$Fe(OH)_2/Zr(OH)_4$

UTEVA: Np, Zr separation
UTEVA: Np, Zr purification

ICP-MS

Unpredictable behaviour of Zr, because
HF is used to dissolve ZrO_2 ↔
ZrF_4 is not retained on UTEVA

DGA procedure:

DESTRUCTION

DGA: Np, Zr separation
UTEVA: Np, Zr purification

ICP-MS

High and constant
Zr (71%) and Np (84%)
recoveries

Determination of ^{90}Sr in NPP wastes

Sample: 100 mL
Carrier: 10 mg Sr
AAS

Destruction

Ca(Sr) oxalate precipitation

Sr Resin

time of separation of Y from Sr

Sr oxalate

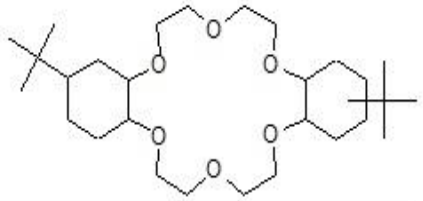
Sr yield: gravimetry/ AAS
LSC1
LSC2

^{90}Sr ^{89}Sr

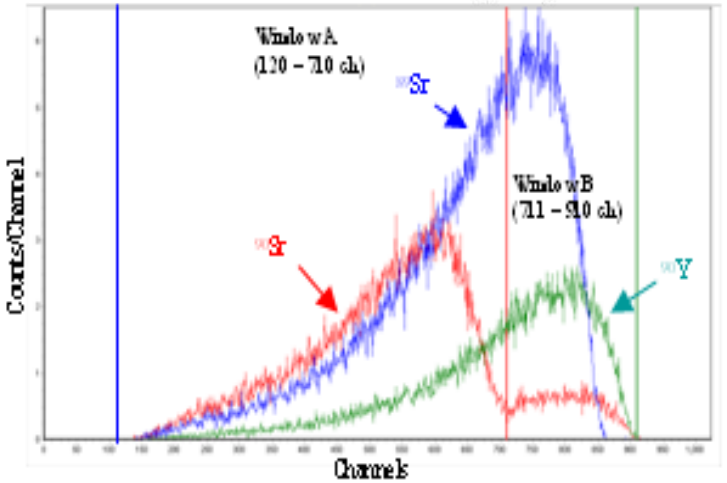
DESTRUCTION
PRECIPITATION, ADSORPTION
EXTRACTION, CHROMATOGRAPHY

Sr yield is determined from gravimetry/AAS.

High selectivity for Sr is assured by the use of Sr selective crown ether: Sr Resin



By repeated measurement both ^{90}Sr and ^{89}Sr are determined.



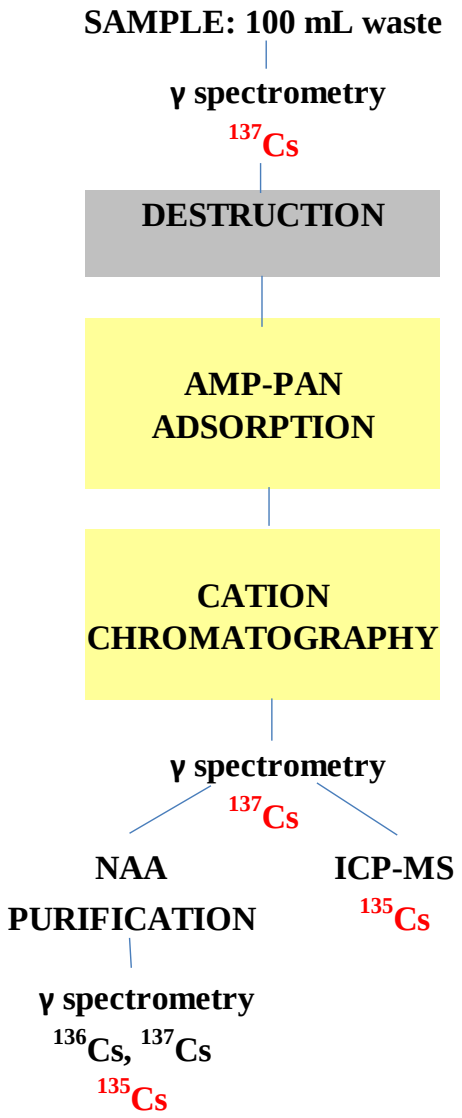
The method is combined with the determination of actinides.

VAJDA N, GHODSESPHAHANI A, COOPER E, DANESI PR: DETERMINATION OF RADIOSTRONTIUM IN SOIL SAMPLES USING A CROWN-ETHER. JRNC 162:(2) pp. 307-323. p. 17 (1992)

Results of U, Pu, Np, Am, Cm, Zr, Sr isotope analyses in NPP wastes

Bq/dm³	Sample1 (normal evaporator concentrate)		Sample2 (alpha-cont./emergency evaporator concentrate)		Sample3 (decontamination solution)	
	a	unc(a)				
^{3}H	4,00E+05	2,0E+04	2,12E+05	1,1E+04	7,68E+04	3,8E+03
^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,1E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{94}Nb	7,00E+02	1,40E+02	N/A		8,50E+02	1,00E+02
^{99}Tc	< 1,7E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{125}Sb	≤ 5,0E+02		N/A		9,00E+03	8,00E+02
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,7E-01	
^{234}U	2,20E-01	2,05E-02	≤ 1,67E+03		3,39E+01	6,88E+00
^{235}U	≤ 1,13E-02		≤ 1,66E+03		≤ 7,73E+00	
^{237}Np	4,55E-03	5,27E-04	1,38E-02	7,95E-04	3,36E-03	1,94E-04
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
^{238}U	1,49E-01	1,64E-02	≤ 1,14E+03		8,79E+00	3,60E+00
$^{239,240}Pu$	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

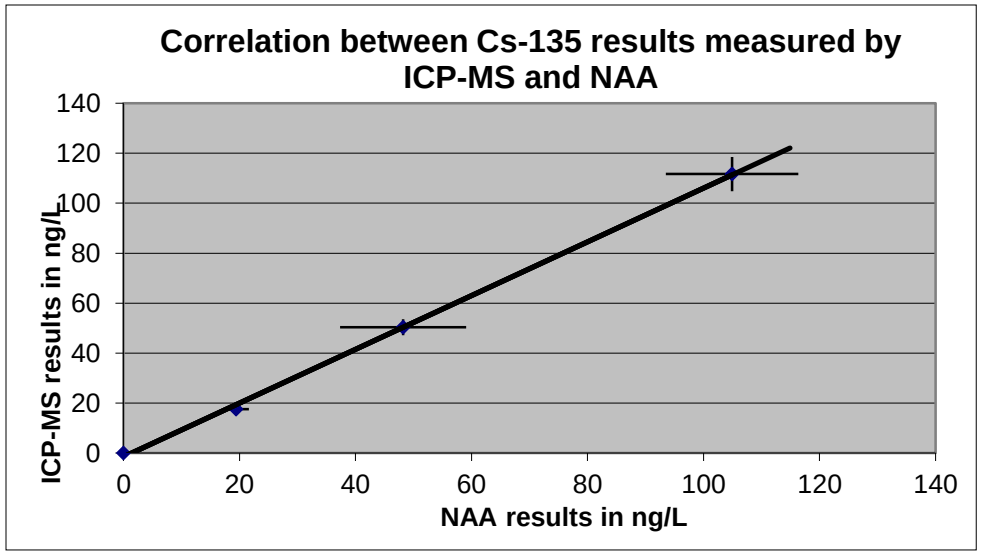
Determination of ^{135}Cs in NPP wastes



AMP is a selective ion exchanger for Cs.

Small cation column is used to separate Ba, the isobar interference for ^{135}Cs in ICP-MS.

NAA and ICP-MS results correlated well:



Measured concentrations in wastes: 20-100 ng/L ~ 1-5 Bq/L

Nagy P, Vajda N, Sziklai-László I, Kovács-Széles É, Simonits A: Determination of 135Cs in nuclear power plant wastes by ICP-MS and k 0-NAA. JRNC 299:(2) pp. 615-627. (2014)

Determination of ^{55}Fe, ^{59}Ni, ^{63}Ni in NPP wastes

SAMPLE
Carriers: 6 mg Fe, 6 mg Ni

DESTRUCTION

MIBK
EC

Fe yield: AAS

LSC/X spectrometry
^{55}Fe

DMG
EC

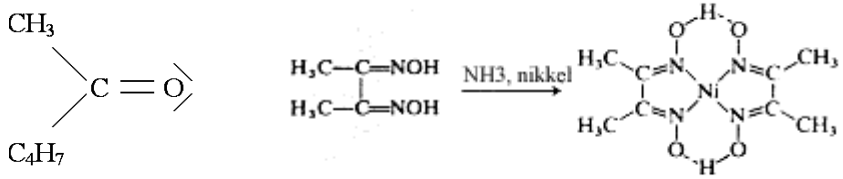
DMG precipitate

Ni yield: AAS

X spectrometry
^{59}Ni

LSC
^{63}Ni

Home made EC resins are used:



a unc(a)

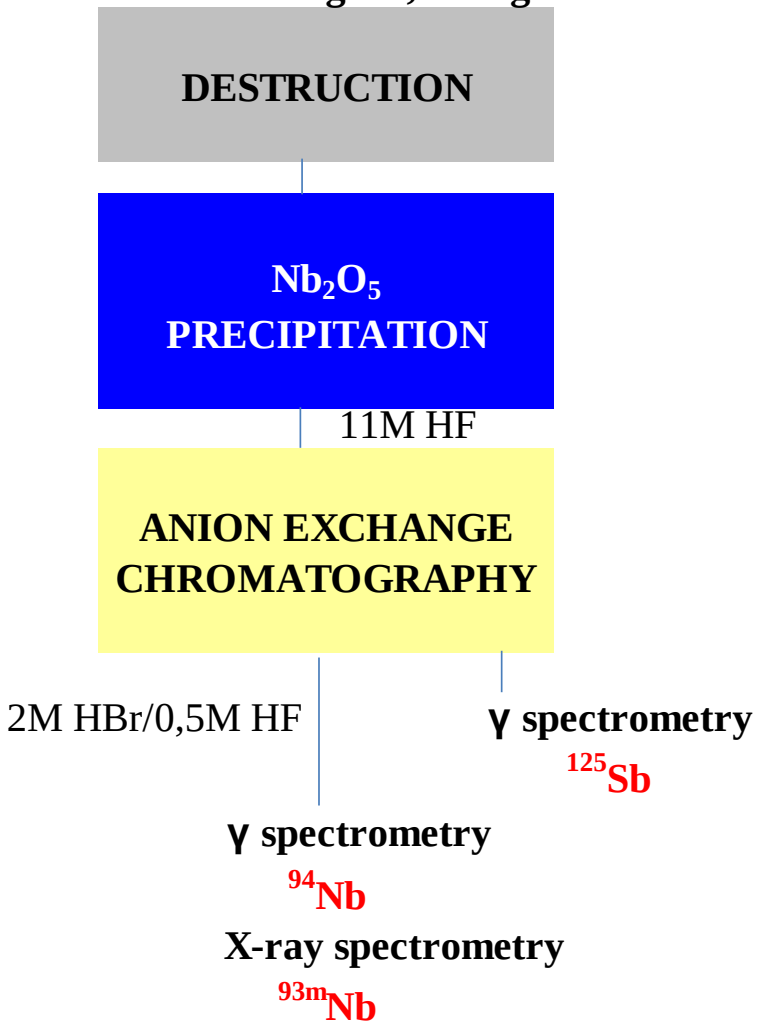
Bq/dm³	Sample1 (normal evaporator concentrate)		Sample2 (alpha-cont./emergency evaporator concentrate)		Sample3 (decontamination solution)	
^{3}H	4,00E+05	2,0E+04	2,12E+05	1,1E+04	7,68E+04	3,8E+03
^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,07E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{99}Tc	< 1,67E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,67E-01	
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
$^{239,240}Pu$	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

Determination of ^{93m}Nb, ^{94}Nb, ^{125}Sb in NPP wastes

Sample: 100 mL waste

Tracers: ^{95}Zr-^{95}Nb, ^{124}Sb

Carriers: 10 mg Nb, 10 mg Sb



Results of analysis

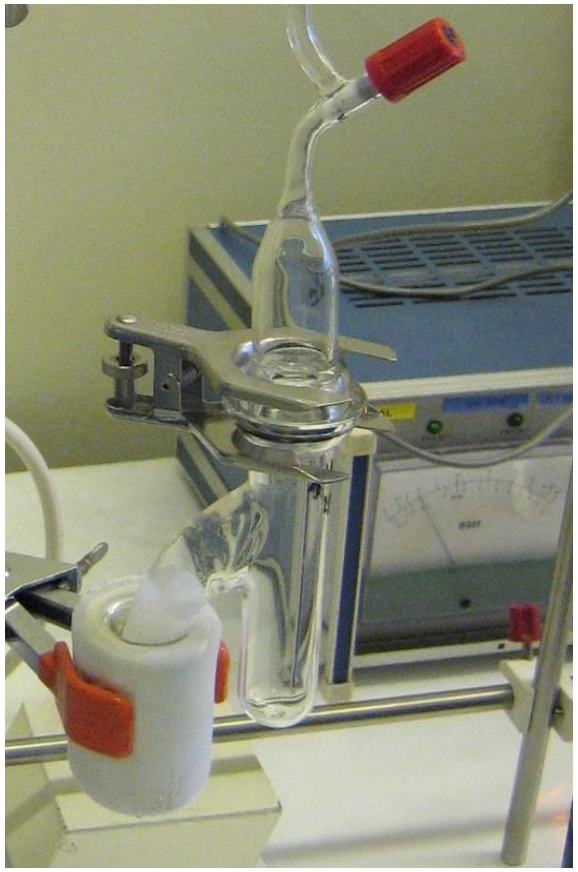
Activity concentration of ^{93m}Nb is usually close to LD.

Bq/dm³	Sample1 (normal evaporator concentrate) a	Sample1 unc(a)	Sample2 (alpha-cont./emergency evaporator concentrate)		Sample3 (decontamination solution)	
^{3}H	4,00E+05	2,0E+04	2,12E+05	1,1E+04	7,68E+04	3,8E+03
^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,1E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{94}Nb	7,00E+02	1,40E+02	N/A		8,50E+02	1,00E+02
^{99}Tc	< 1,7E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{125}Sb	≤ 5,0E+02		N/A		9,00E+03	8,00E+02
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,7E-01	
^{234}U	2,20E-01	2,05E-02	≤ 1,67E+03		3,39E+01	6,88E+00
^{235}U	≤ 1,13E-02		≤ 1,66E+03		≤ 7,73E+00	
^{237}Np	4,55E-03	5,27E-04	1,38E-02	7,95E-04	3,36E-03	1,94E-04
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
^{238}U	1,49E-01	1,64E-02	≤ 1,14E+03		8,79E+00	3,60E+00
^{239,240}Pu	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

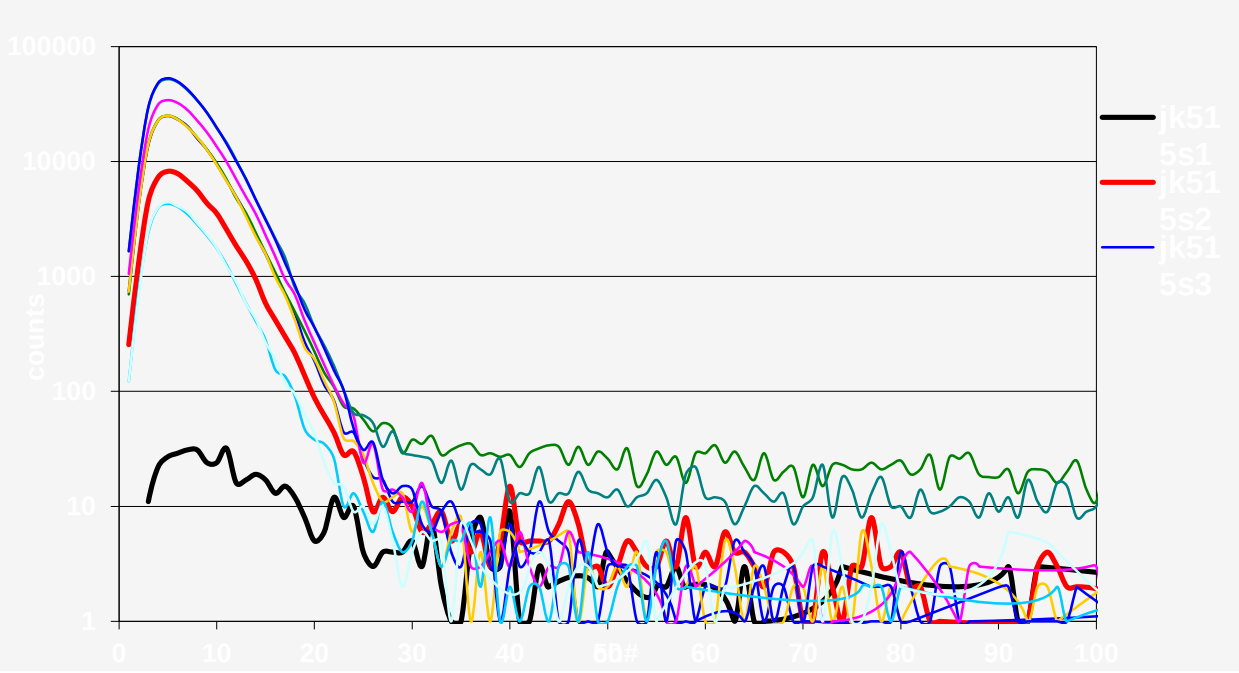
Determination of DTM nuclides at INSTITUTE FOR NUCLEAR RESEARCH OF HUNGARIAN ACADEMY OF SCIENCES (INR HAS) - ISOTOPTECH Co.

Determination of ^{3}H in NPP wastes

Low-pressure cold-distillation



LSC counting



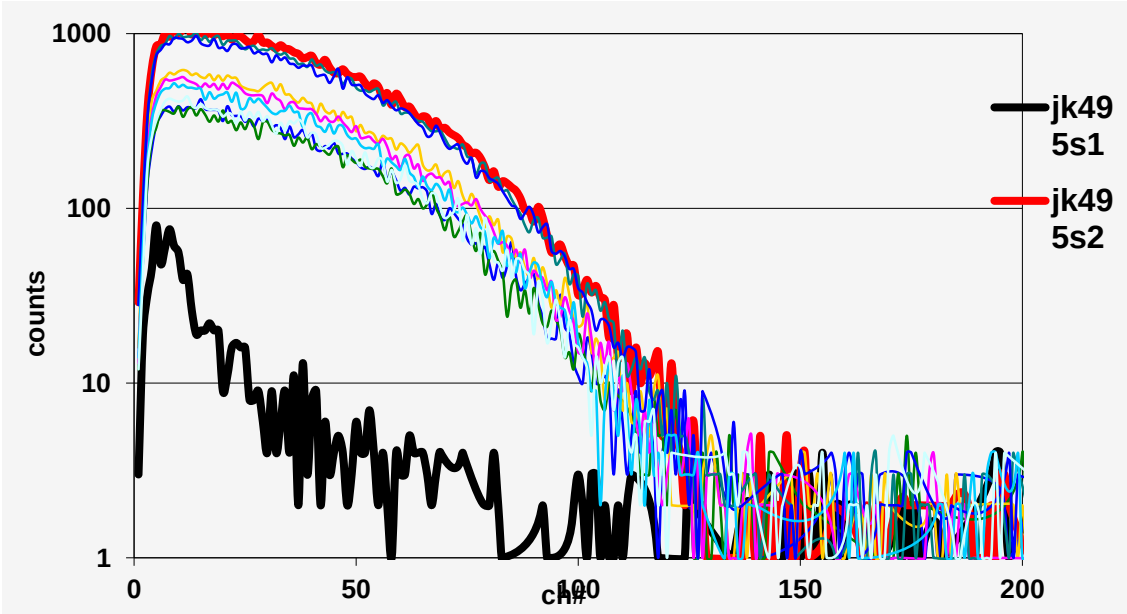
Determination of ^{14}C in NPP wastes

Acidic destruction and 2-step trapping of CO_2

1. step: total oxidisation of the sample, CO_2 is trapped in $Ba(OH)_2$ as $BaCO_3$
2. step: CO_2 is released from $BaCO_3$ and trapped in NaOH as $NaHCO_3$

LSC counting

NaOH solution in HionicFluor



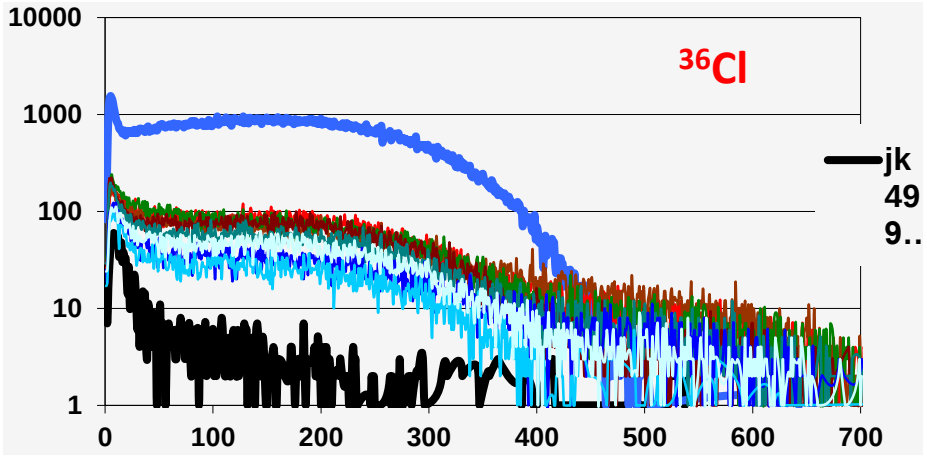
A set of results for 3 sample types

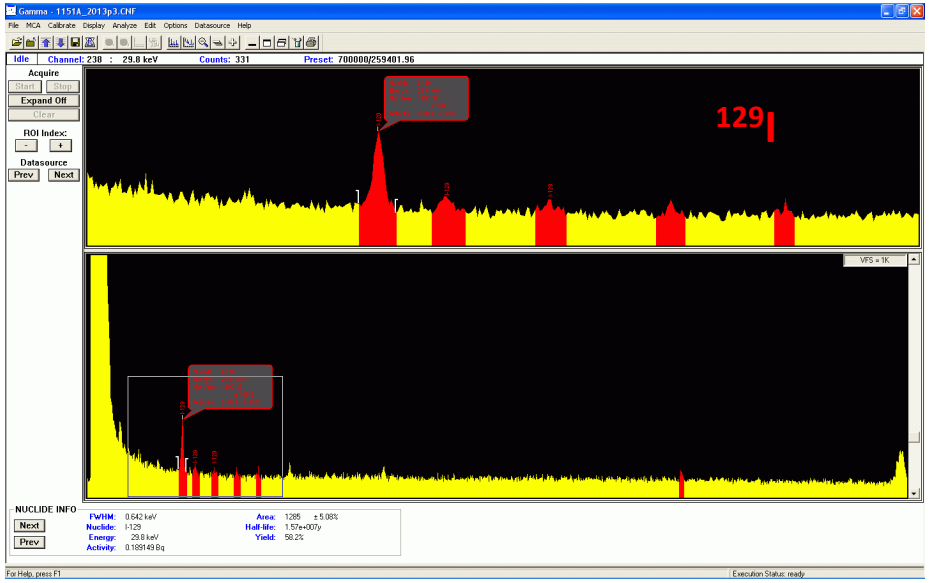
a unc(a)

Bq/dm³	Sample1 (normal evaporator concentrate)		Sample2 (alpha-cont./emergency evaporator concentrate)		Sample3 (decontamination solution)	
^{3}H	4,00E+05	2,0E+04	2,12E+05	1,1E+04	7,68E+04	3,8E+03
^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,07E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{99}Tc	< 1,67E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,67E-01	
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
$^{239,240}Pu$	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

Determination of ^{36}Cl and ^{129}I in NPP wastes

Destruction with ccH_2SO_4,
I_2 formed is trapped by CCl_4, backextracted as I^-,
precipitated as AgI, yield by gravimetry,
HCl is trapped in H_2O, yield by ion chromatography





A set of results for 3 sample types

a unc(a)

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^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,07E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{99}Tc	< 1,67E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,67E-01	
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
$^{239,240}Pu$	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

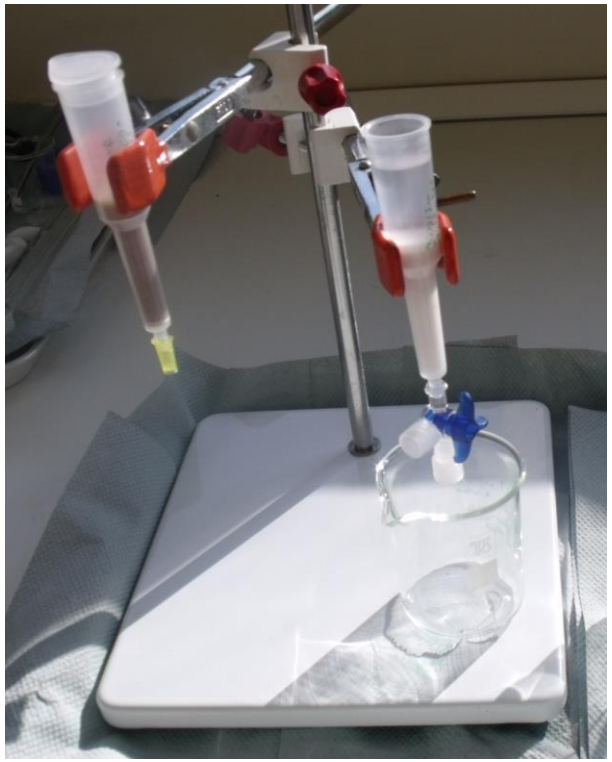
Determination of ^{108m}Ag and ^{99}Tc in NPP wastes

Concentration of Ag using ultrafiltration

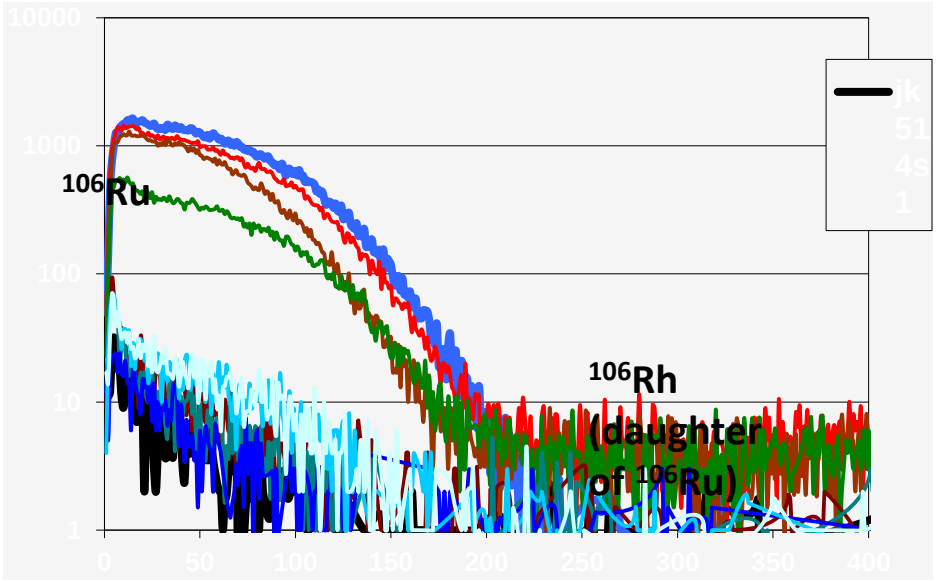
Measurement by gamma spectrometry, e.g.

Isotope	Activity concentration (Bq/dm^3)
^{108m}Ag	(7,98±0.21) E+02
^{110m}Ag	(7,29±0.06) E+03

Separation of Tc from the Ag permeate:
removal of water content, acidic destruction,
precipitation with H_2S,
purification with cation exchange and
extraction chromatography using TEVA resin



Measurement of ^{99}Tc-TEVA using Insta Gel by LSC



A set of results for 3 sample types

a unc(a)

Bq/dm³	Sample1 (normal evaporator concentrate)		Sample2 (alpha-cont./emergency evaporator concentrate)		Sample3 (decontamination solution)	
^{3}H	4,00E+05	2,0E+04	2,12E+05	1,1E+04	7,68E+04	3,8E+03
^{14}C	1,01E+04	1,01E+03	2,96E+03	2,96E+02	3,48E+02	3,48E+01
^{36}Cl	3,65E+01	1,26E+01	9,03E+01	3,46E+01	< 1,07E+01	
^{55}Fe	2,44E+05	2,44E+04	9,37E+06	9,36E+05	1,39E+05	2,08E+04
^{63}Ni	4,41E+04	2,21E+03	1,75E+06	3,49E+05	2,78E+05	5,56E+04
^{90}Sr	4,92E+02	3,32E+01	1,68E+06	2,35E+05	3,04E+05	2,33E+04
^{93}Zr	3,52E+02	8,89E+00	8,03E-01	2,43E-02	5,06E-02	1,39E-03
^{99}Tc	< 1,67E-01		1,77E+01	5,35E+00	1,06E+01	2,07E+00
^{108m}Ag	1,38E+02	8,81E+00	1,34E+04	7,98E+02	1,32E+02	4,71E+00
^{129}I	1,94E-01	1,75E-02	7,32E-01	8,04E-02	< 2,67E-01	
^{238}Pu	1,29E+01	4,65E-01	9,37E+04	3,38E+03	1,38E+04	4,48E+02
$^{239,240}Pu$	9,39E+00	3,53E-01	9,84E+04	3,53E+03	1,25E+04	4,08E+02
^{241}Am	7,47E+00	2,60E-01	8,73E+04	3,23E+03	1,33E+04	4,55E+02
^{244}Cm	3,24E+00	1,24E-01	1,22E+04	7,27E+02	2,77E+03	1,18E+02

Methods under development based on ICP-MS/MS measurement

for the sensitive determination of ^{79}Se, ^{107}Pd, ^{129}I, ^{151}Sm, ^{147}Pm

Scaling factors for NPP waste characterization

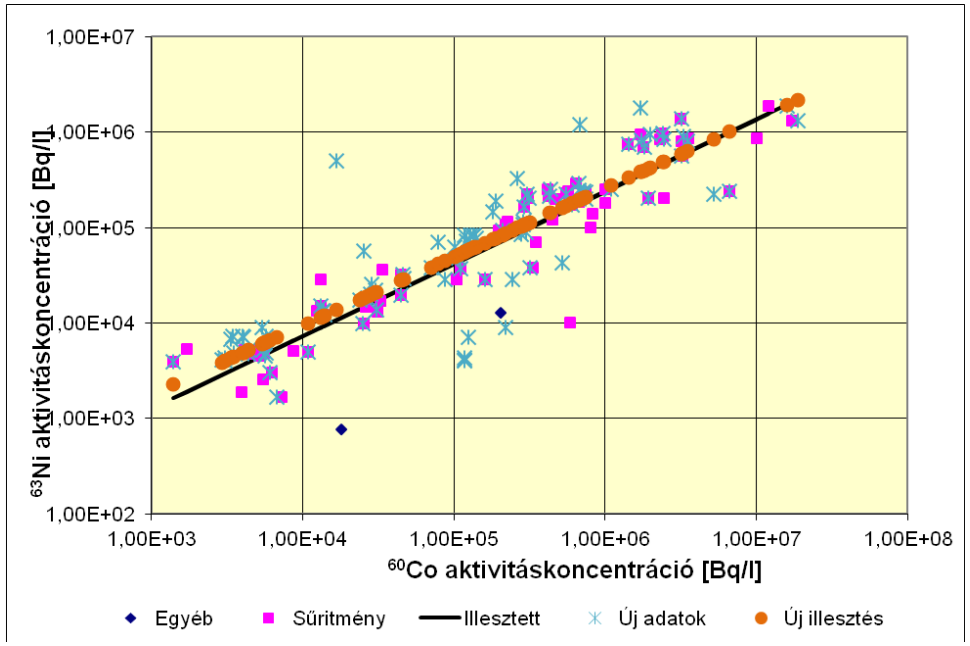
Determination of SF for liquid wastes at NPP Paks

Scaling factors are determined from the analysis of liquid wastes:

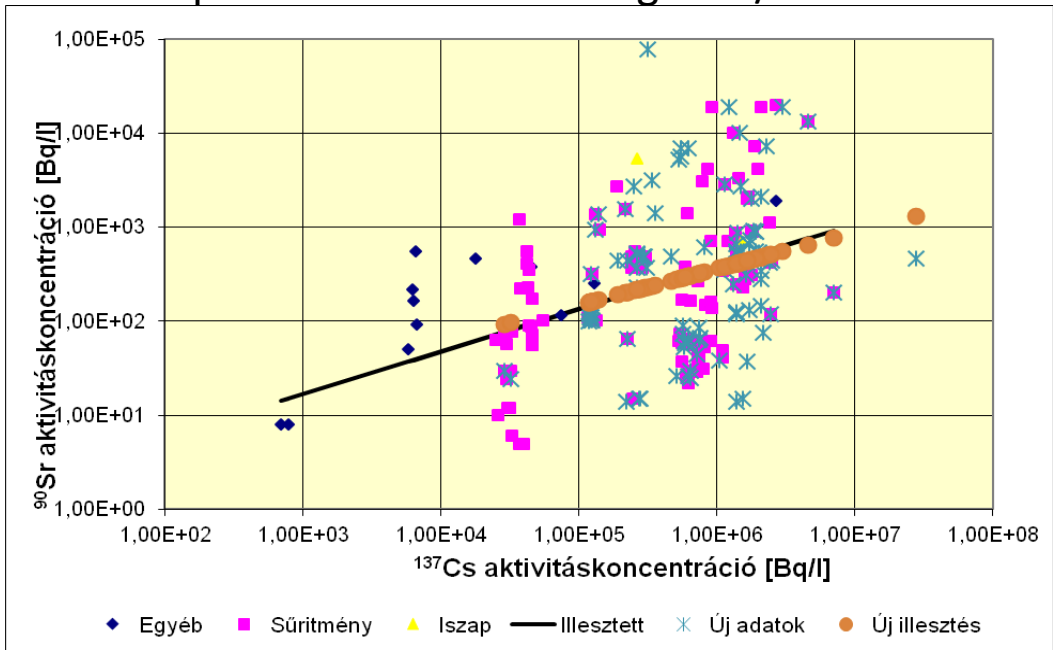
$$C_{DTM}=b*(C_{KN})^{m}$$

C_{DTM} acivity concentration of DTM nuclide
C_{KN} acivity concentration of key nuclide
m, b parameters

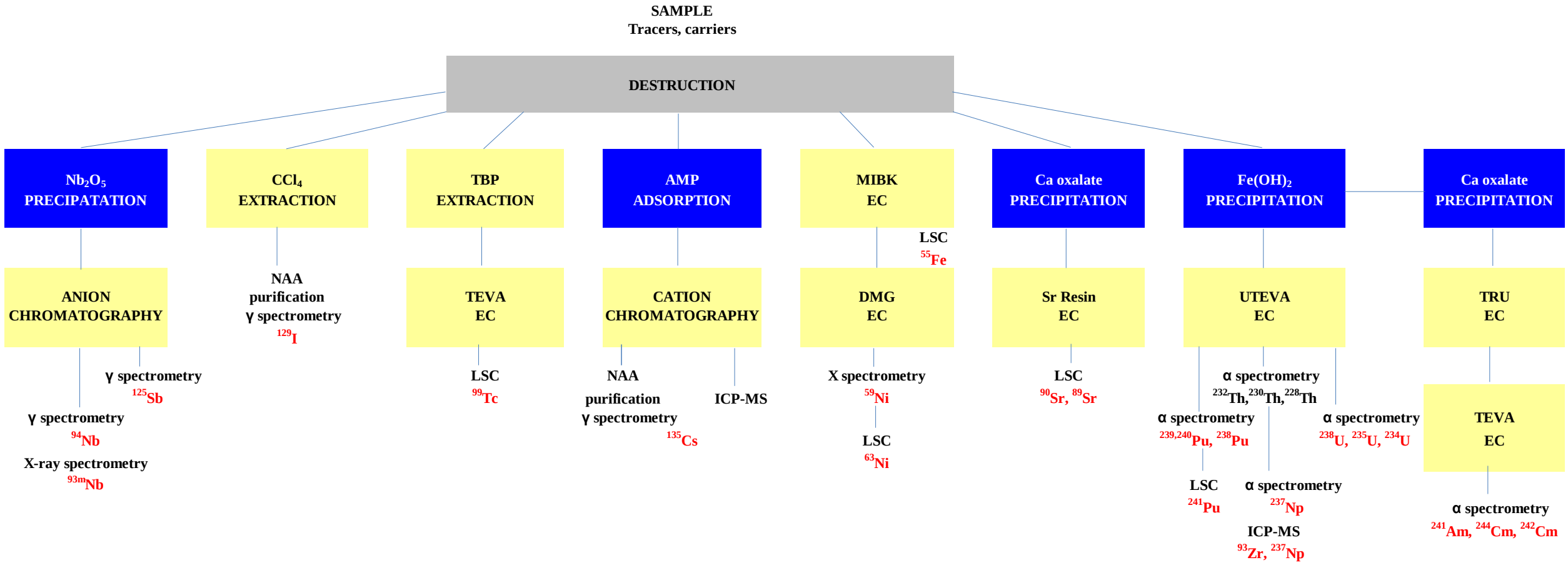
Example for EXCELLENT fitting: $^{63}Ni/^{60}Co$

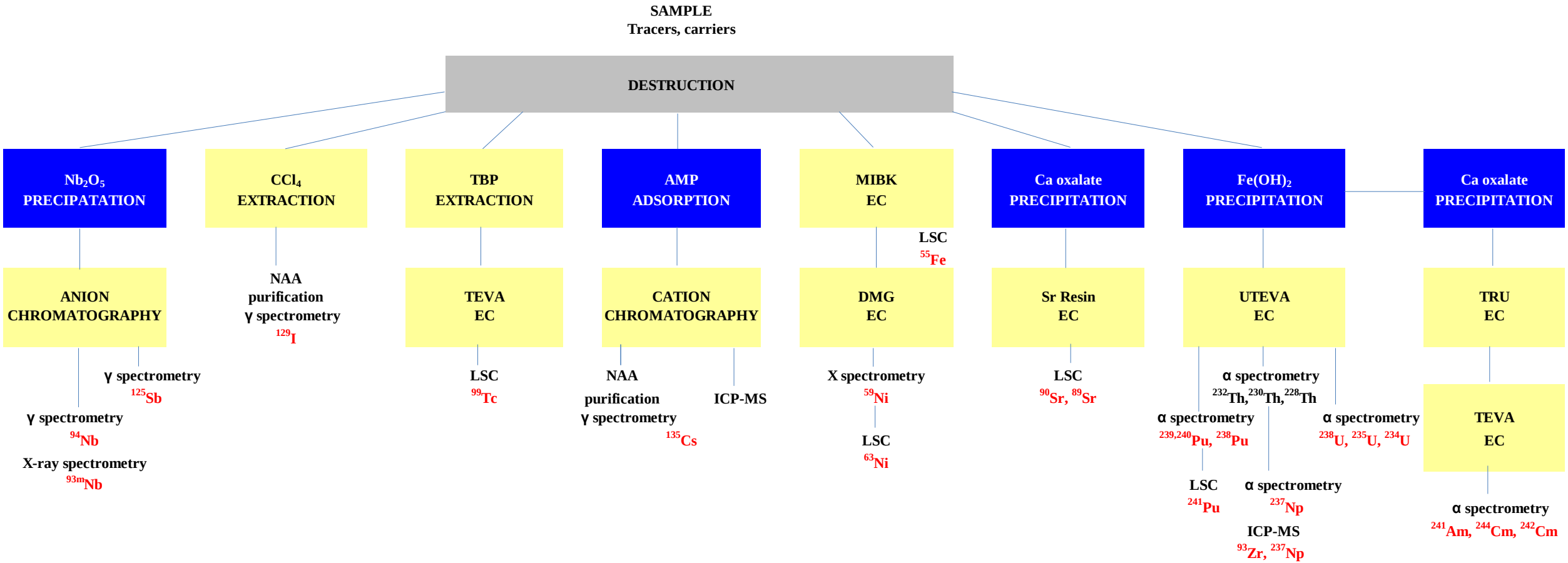


Example for ACCEPTED fitting: $^{90}Sr/^{137}Cs$



Instead of a summary...





Thank you for your attention!