AUGMENTED CINCH

(Project Number: 945301)

DELIVERABLE D3.5

Learning resources based on innovative didactical approaches

Lead Beneficiary: POLIMI

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CO	Confidential, only for Beneficiaries of the A-CINCH project	

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EXECUTIVE SUMMARY

This document describes the work done by Leibniz University of Hanover (LUH), Politecnico di Milano (POLIMI) and Josef Stefan Institute (JSI) to develop new learning materials to be used in blended learning approaches.
A new ISE based on the Autodeposition lab Robolab has been developed by LUH and made available on the IRS website: http://ibe.irs.uni-hannover.de/ibes/de/RoboLabs/index.html as well as the Twillo platform. This will assure the sustainability of this resource beyond the end of the project.

The *Basic course on analytical radiochemistry* provided by JSI has been upgraded by enlarging the laboratory videos part. To the purpose, 14 new videos have been produced dealing with the analysis of new matrices, such as sediments and biological materials (fish), for the determination of Po-210 and Pb-210, covering also the initial sample preparation. The videos are all freely available on the following web page: http://videolectures.net/meet-cinch_courses/. The work done contributes to improve the educational video materials used in the course in a flipped classroom approach.

Finally, an in-class activity has been designed by POLIMI dealing with the hydrometallurgical processes aiming to make nuclear energy more environmentally sustainable and socially acceptable, by means of the reprocessing and recycling of the most hazardous components of the spent nuclear fuel. To this purpose, POLIMI developed a didactical resource to be used in a problem-based learning approach focused on the advanced partitioning of PUREX raffinate.

CONTENT

1 INTERACTIVE SCREEN EXPERIMENT

1.1 Introduction

Interactive screen experiments (ISE) are a representation of real experiments, where the real experiments are reproduced as accurately as possible by video sequences on the computer screen. The model for the new designed ISE is the remote-controlled PAuLa. In contrast to the remotely controlled experiment, the access to the ISE is unlimited and several users can perform the experiment simultaneously. Digital experiments cannot replace real hands on training in the laboratory. However, especially for pupils, digital experiments offer the possibility to gain experience in the field of radioactivity and to inspire them at an early stage. This is otherwise hardly possible, as schools often do not have handling authorizations for radioactive sources and furthermore access to radionuclide laboratories is limited for pupils who are not yet full-age. And for students, virtual experiments can be an alternative if they do not have access to the laboratory for various reasons, too.

1.2 Programmable Autodeposition Lab Paula

__P__rogrammable __Au__todeposition __La__b PAuLa

The RoboLab Paula is about the autodeposition of technetium on metal strips. The success of the deposition can then be checked by measuring with a GEIGER-MÜLLER counter. The experiment is well suited to introduce pupils and students to the field of radiochemistry, as it has both: with the autodeposition an (electro-) chemical component and, through detection with the GEIGER-MÜLLER counter, a radioanalytical component. Figure 1 shows the user interface of the new ISE, which is based on the one of the RoboLab. To simulate the live video, the RoboLab was reconstructed and for every action, the user can initiate with the controlling buttons, the movement auf the robotic arm filmed. To make the ISE and its didactic content easily accessible to users, the manual has been revised. It now includes a theory section on beta decay, autodeposition, technetium and radiometric detection. Parts of the script are too complex for high school students. However, for the sake of completeness, they have been included so that teachers can prepare in detail for conducting the experiment and hand (parts of) the manual out to their pupils. Students should be able to carry out the experiment independently with the help of the instructions.

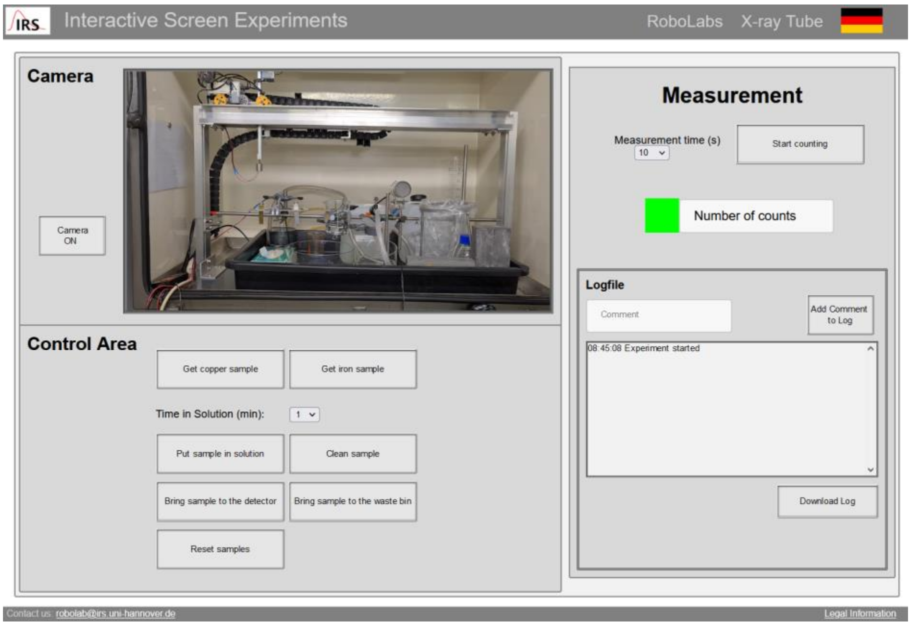

Figure 1. User interface of the ISE PauLa

The new ISE and the other ISE are available under:
http://ibe.irs.uni-hannover.de/ibes/en/RoboLabs/index.html
On the website of the ISEs there is now also a download link for the instructions and other materials concerning the ISEs.

1.3 Conclusion

The ISEs provide an adequate backup for the RoboLabs in case they are not operational due to technical problems. In addition, ISEs do not require maintenance and can continue to operate when the project ends and there is no further funding for maintenance. Thus, the development of the ISE is an important step towards ensuring that the achievements of the CINCH projects will be available beyond the end of the project.

In order to make the ISEs' offer known outside the CINCH community, LUH plans to make the material available on *Twillo*, a platform for OER funded by the federal ministry for science and culture of Lower Saxony. The platform will be presented to the other project partners at the next project meeting.

2 VIDEO MATERIALS

2.1 Introduction

Acquiring the needed practical experience in every activity is often a difficult task, that can be strongly limited by laboratory's availability, laboratory's size, as well as student's geographical distribution and the availability of financial support.
In this perspective, laboratory video materials could be very effective in offering to the students a first plunge in the experimental and practical tasks. The enhancement of a course with laboratory video materials could favour the active involvement of students and strongly boost their training also on the practical aspects.

2.2 Laboratory video materials for *Basic course on analytical radiochemistry*

14 laboratory videos have been designed, recorded and produced for upgrading the online part of the flipped classroom teaching concept adopted in the *Basic course on analytical radiochemistry,* provided at the Jozef Stefan Institute in Ljubljana.
Educational videos explain in a very detailed way the determination of Po-210 and Pb-210 in fish and sediment samples, with the following learning objectives:

- to get familiar with the preparation of fish and sediment for the subsequent Po-210 and Pb-210 determination
- to gain understanding of principles of acid digestion of fish and sediment f
- to be able to understand Po-210 and Pb-210 separation procedure using Sr Resin
- to be able to calculate final results of activity and uncertainty for Po-210 and Pb-210 in fish and sediment sample.

The laboratory videos have been integrated into the course on the CINCH Moodle platform (https://moodle.cinch-project.eu/course/index.php?categoryid=57) and they are also available at the following link: http://videolectures.net/meet-cinch_courses/ (see Figures 2 and 3).

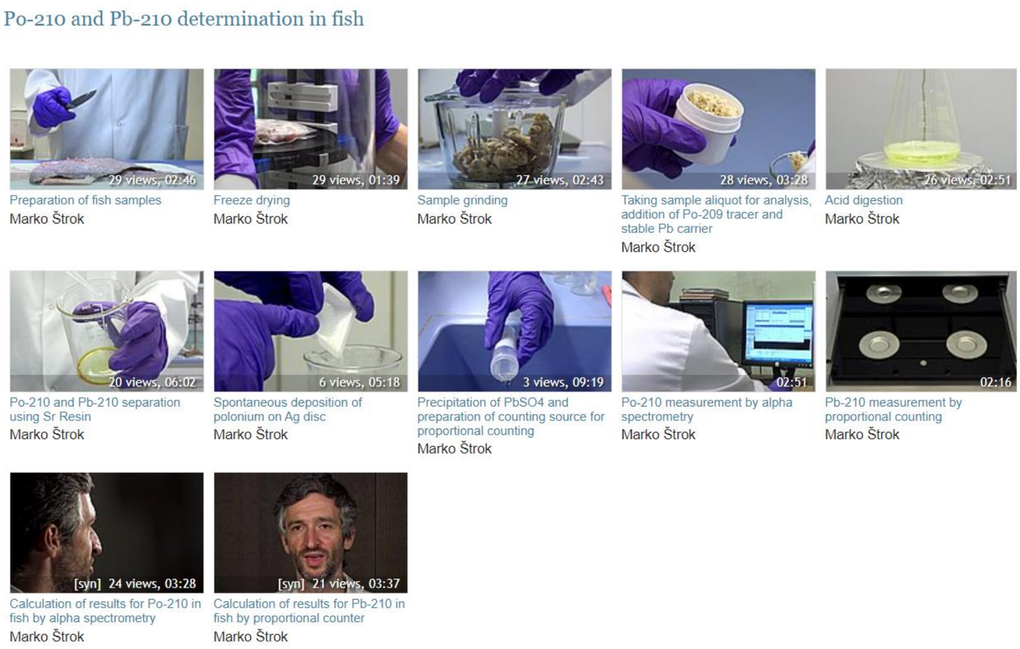

Figure 2. Laboratory videos on the determination of Po-210 and Pb-210 in fish

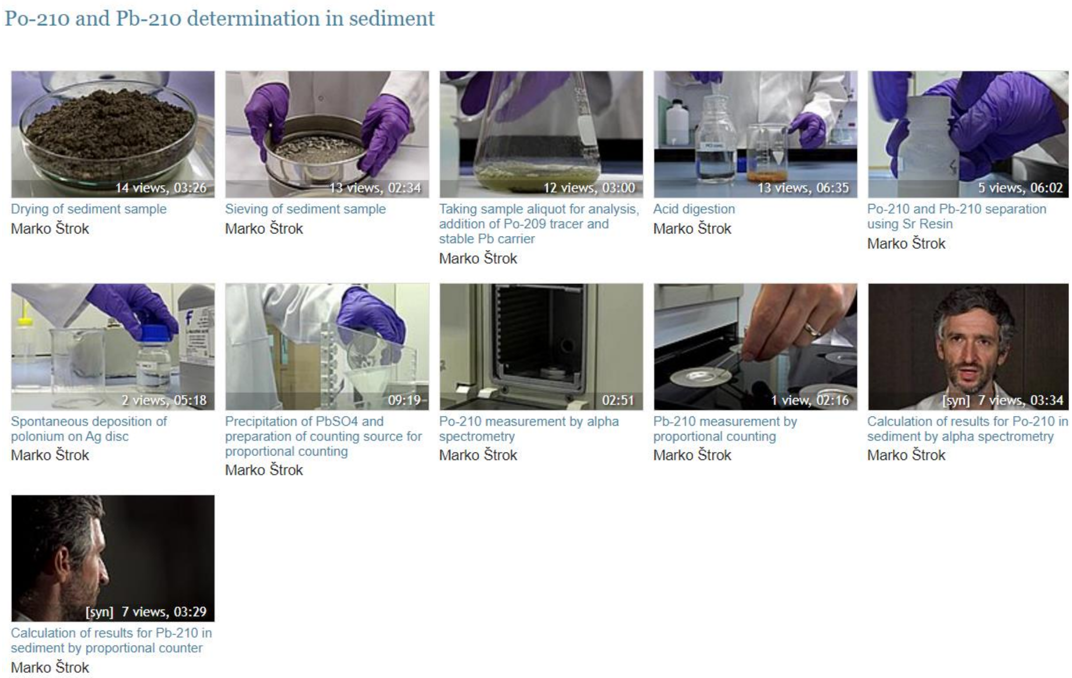

Figure 3. Laboratory videos on the determination of Po-210 and Pb-210 in sediments

2.3 Conclusion

The laboratory video materials are thus freely available and they are ready to be used for blended teaching approaches to provide basics of analytical radiochemistry.

3 DIDACTICAL RESOURCES FOR PROBLEM-BASED LEARNING APPROACH

3.1 Introduction

The problem-based learning approach could be a valuable way to actively stimulate the students and let them acquire a durable knowledge by training also soft skills.
To solve the problem presented, the student has to analyse it, identify the already acquired competences useful for the case, search for the missing information, propose a solution and explain it to an audience. Furthermore, working in team to solve this problem demands the student to practice her/his teamwork skills, such as the social skills, the capacity of managing conflicts and to communicate with others.

3.2 Exercise on advance partitioning of PUREX raffinate

The activity was designed to be offered within an academic course dealing with nuclear waste treatment by hydrometallurgy. Indeed, the activity is strictly related to the advanced partitioning of the PUREX raffinate, the outgoing stream of the PUREX process. After the removal of U and Pu in the PUREX process, the outgoing stream could be further processed to separate minor actinides, that are responsible for the long-term radiotoxicity of the remaining spent nuclear waste, by advanced partitioning processes.
The activity requires that the topic and some fundamentals are previously presented to the class. Afterwards, the problem is presented and explained to the class by the teacher. To introduce the exercise, a scenario was defined and the problem was clearly expressed.
In the activity proposed, students are asked to identify themselves with scientists who are working in a radiochemistry laboratory to design a hydrometallurgical process able to separate Minor Actinides from the PUREX raffinate.
The activity is guided by progressive questions to answer which you need to use your competences (acquired during the course) and some technical data provided in the form of schemes, tables, figures or graphs. For example, they have to decide which separation strategy they would like to adopt since it strongly affects the subsequent selection of the ligands to be used in the process. All the necessary technical data could be provided at the beginning or step by step to facilitate the students.
Some hints or supporting materials could be proposed to stimulate the active involvement of the students or to address them in case of need.
The activity was designed to be performed i) in small groups of students in classroom under the supervision of the teacher in 2-4 hours or ii) as homework to be developed in team and presented to the class in a flipped classroom approach.
The activity is organized as follow:

a. Scenario
b. Problem statement
c. Activity n°1: Propose your separation strategy and discuss its potential strengths and weaknesses.
d. Activity n°2: According to the information available and the strategy chosen, which extractants and diluents do you select? Technical data are provided.
e. Activity n°3: According to the data available, which concentrations for the extractants and nitric acid do you propose for the extraction section? Additional technical data could be provided.
f. Activity n°4: Based on the available data, is it necessary to add the scrubbing section? If so, which aqueous phase do you propose to use for the scrubbing section? Additional technical data could be provided.

g. Activity n°5: Based on the available data, is it necessary to use a complexing agent? If so, which one and at what concentration do you propose to use for the stripping section? Additional technical data could be provided.

Concerning the expected learning outcomes, the student will be able to:

- analyse the problem and identify the requirements to be fulfilled;
- select a strategy that enable to reach the purpose
- read tables and graphs and derive useful suggestions from them;
- identify and select the parameters relevant for the problem;
- propose a solvent formulation suitable for the purpose on the basis of the technical data provided;
- define a qualitative process scheme;
- present and explain the proposal to the class;
- discuss and decide collaboratively.

The didactical material is available in the form of a ppt presentation and it is reported in ANNEX I. It could be offered to students in different ways, depending on the teaching approach chosen.

3.3 Conclusion

The didactical material is freely available and it could be easily used within the framework of a blended teaching approach. It will be proposed within the course "*Analytical methods and processes for waste characterization and valorisation*" addressed to future Nuclear and Chemical engineers at Politecnico di Milano.

GENERAL CONCLUSIONS

The work done by LUH, JSI and POLIMI has led to produce new didactical materials in a sustainable perspective. They address different radiochemical aspects and are freely available to teachers who would like to innovate their teaching by adopting different teaching approaches and tools.

ANNEX I

Didactical material for teamwork

1

Practical exercise on MA Partitioning processes

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Scenario

2

Researchers are working in a radiochemical laboratory.

They are studying effective **hydrometallurgical processes** for the advanced reprocessing of spent nuclear fuel.

Researchers would like to propose technological solutions that could represent feasible options to be **implemented at industrial scale**, making nuclear reprocessing as much **sustainable** as possible.

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Problem statement

3

Researchers would like to develop a process aiming at the **selective separation of trivalent MA from PUREX raffinate**. So that they could be transmuted into short lived radionuclides and the long-term radiotoxicity of the remaining waste could be strongly reduced.

The extracting system has to be able to **selectively separate** trivalent actinides, such as **Am(III) and Cm(III) from the PUREX raffinate**.
The separation process must be **implemented in a centrifugal contactor battery**.
Spent aqueous and organic solutions have to be **recycled** as much as possible and at the end of their useful life they should be incinerable.
The **fraction containing Am and Cm** has to show characteristics **suitable for** the further **fuel fabrication** step.

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Activity n°1

4

A1. Researchers must identify a separation strategy.
Propose your separation strategy and discuss its potential strengths and weaknesses.

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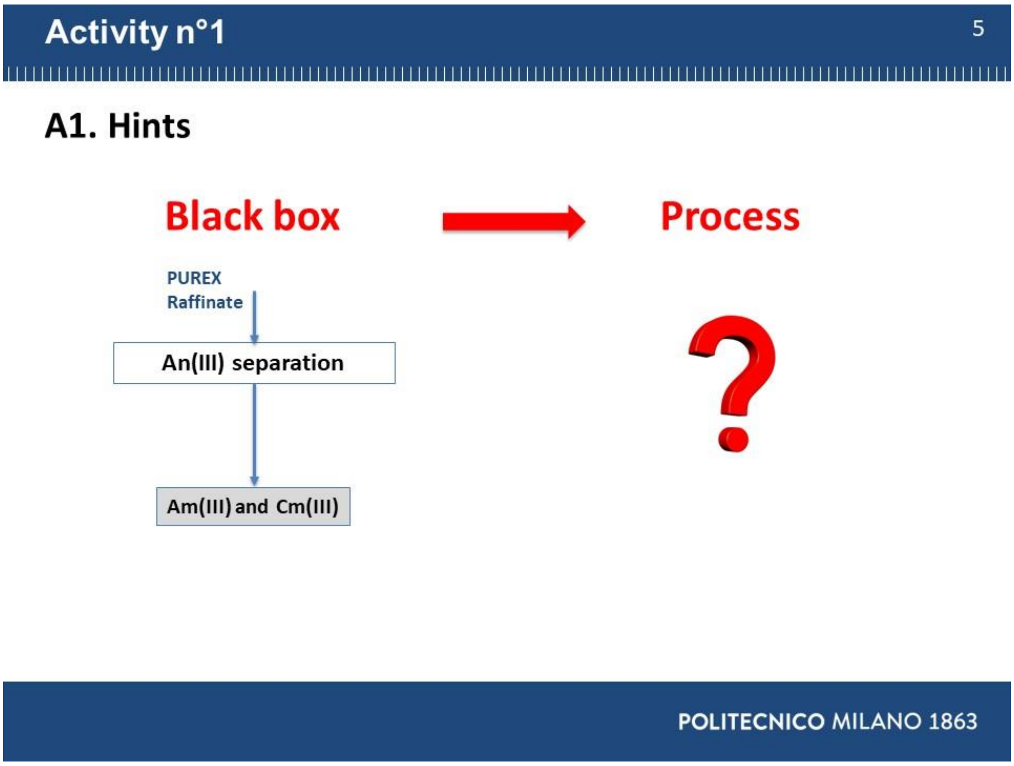
Activity n°1
5
A1. Hints
Black box
Process
PUREX Raffinate
An(III) separation
Am(III) and Cm(III)
?
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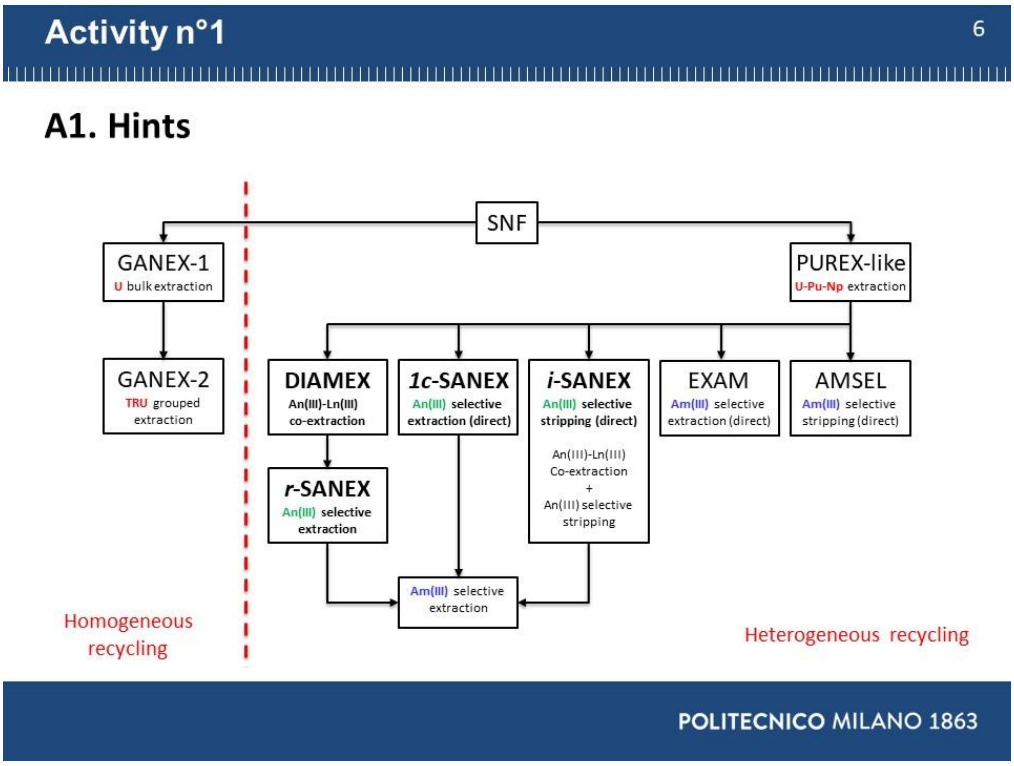
Activity n°1
6
A1. Hints
SNF
GANEX-1
U bulk extraction
GANEX-2
TRU grouped extraction
PUREX-like
U-Pu-Np extraction
DIAMEX
An(III)-Ln(III) co-extraction
r-SANEX
An(III) selective extraction
1c-SANEX
An(III) selective extraction (direct)
i-SANEX
An(III) selective stripping (direct)
An(III)-Ln(III) Co-extraction + An(III) selective stripping
EXAM
Am(III) selective extraction (direct)
AMSEL
Am(III) selective stripping (direct)
Am(III) selective extraction
Homogeneous recycling
Heterogeneous recycling
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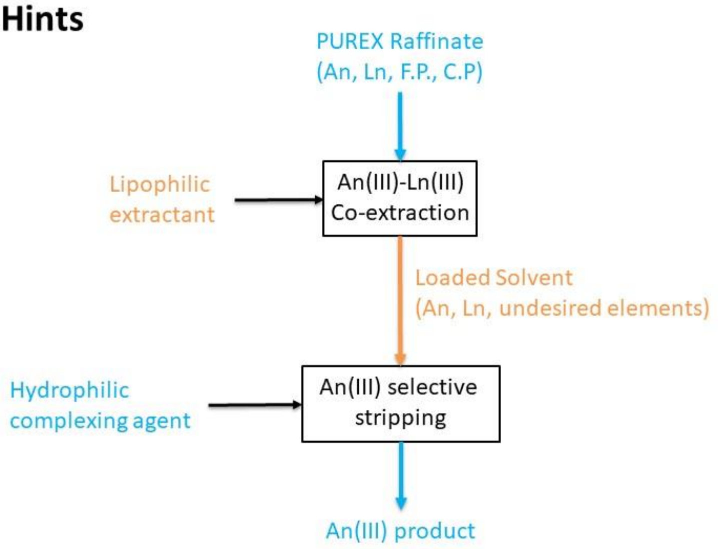
Activity n°1

A1. Hints



Data: Feed composition

PUREX Raffinate composition:

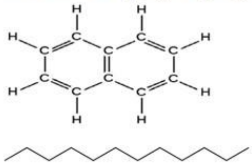
Element	Concentration [mg/L or as shown]	Element	Concentration [mg/L]	Element	Concentration [mg/L]
^{241}Am	5 MBq/L	Ag	11	Pd	204
^{244}Cm	3 MBq/L	Al	2	Rb	59
^{152}Eu	9 MBq/L	Ba	259	Rh	72
Y	79	Cd	22	Ru	355
La	214	Cr	94	Sb	3
Ce	482	Cs	499	Se	35
Pr	189	Cu	19	Sn	0.1
Nd	860	Fe	1900	Sr	161
Sm	144	Mo	658	Te	116
Eu	29	Na	1600	Zr	382
Gd	41	Ni	45		
Masking agent	4.45 mol/L				
	0.05 mol/L				

Data: reagents available

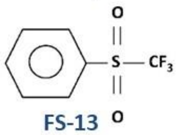
9

Diluents available:

Kerosene, $C_{12}H_{26}$–$C_{15}H_{32}$



Trifluoromethyl phenyl sulphone

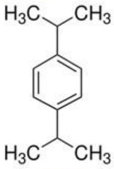


FS-13

hydrogenated tetra propylene

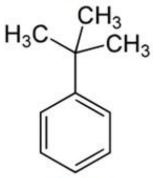
TPH

1,4-diisopropyl benzene



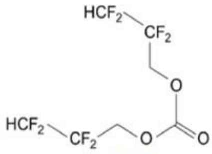
DIPB

Tert butyl benzene



tBuB

Carbonate of 2,2,3,3-tetrafluoropropan-1-ol



BK-1

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Data: reagents available

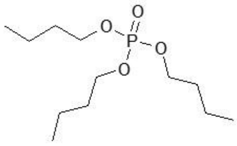
10

Phase modifier available:

1-octanol

Tributyl phosphate

TBP
$(C_4H_9)_3PO_4$



Aqueous phase:

HNO_3 solutions at different acid concentration

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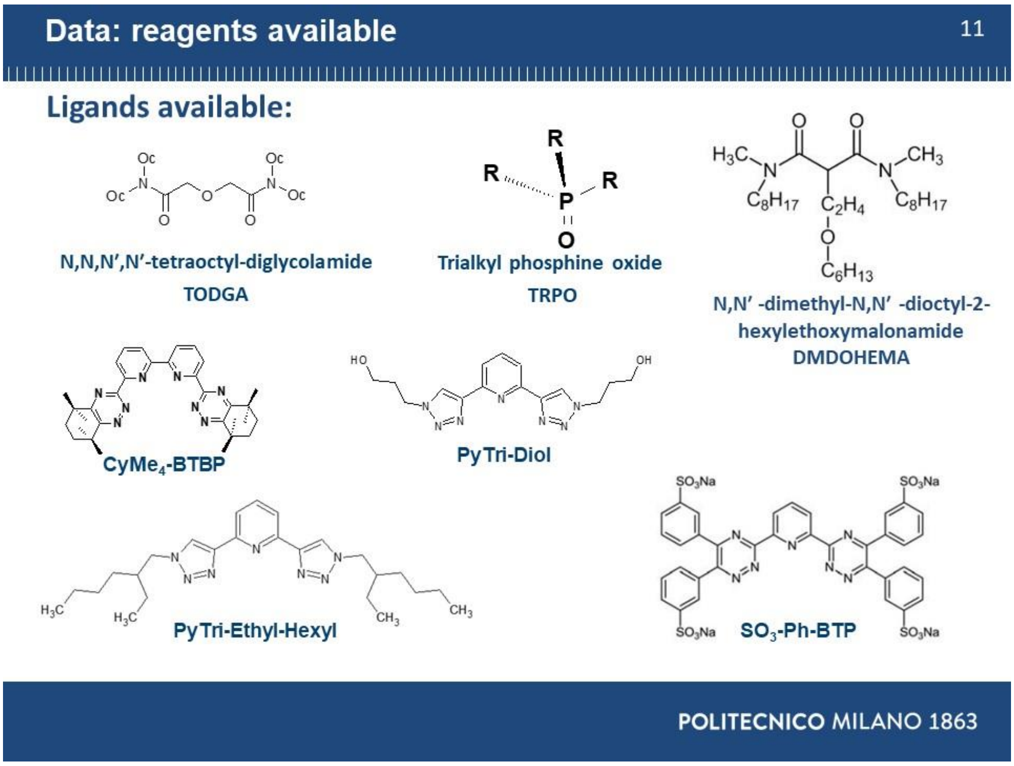
Data: reagents available
11
Ligands available:
N,N,N′,N′-tetraoctyl-diglycolamide
TODGA
Trialkyl phosphine oxide
TRPO
N,N′ -dimethyl-N,N′ -dioctyl-2-hexylethoxymalonamide
DMDOHEMA
CyMe4-BTBP
PyTri-Diol
PyTri-Ethyl-Hexyl
SO3-Ph-BTP
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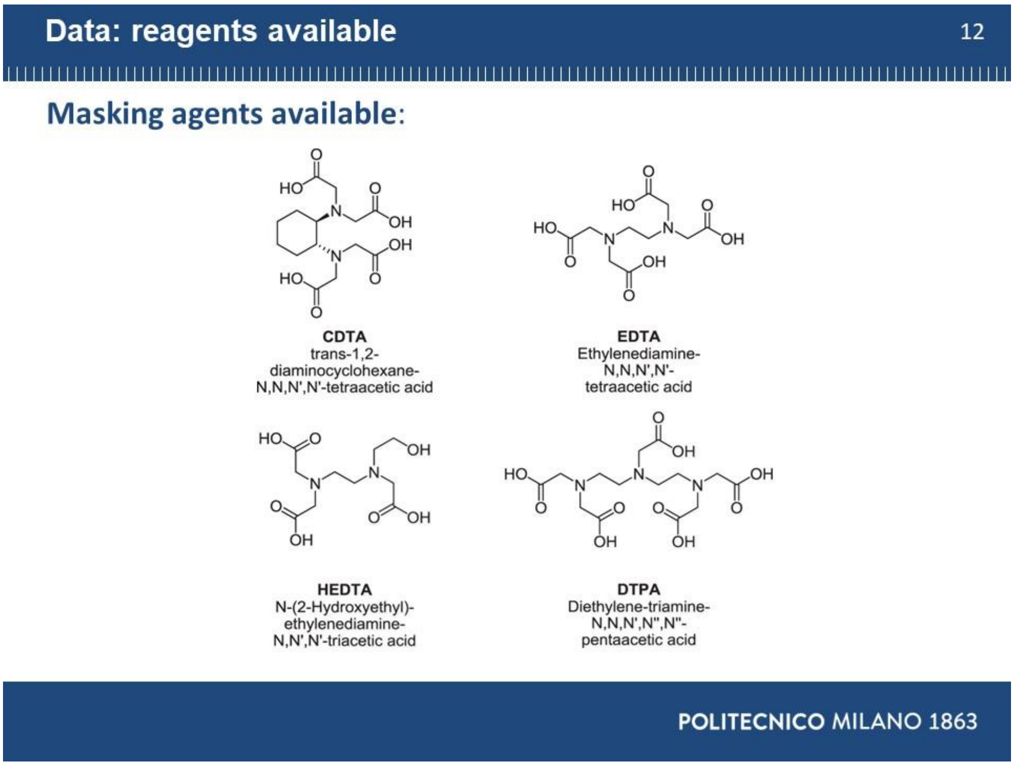
Data: reagents available
12
Masking agents available:
CDTA
trans-1,2-diaminocyclohexane-N,N,N',N'-tetraacetic acid
EDTA
Ethylenediamine-N,N,N',N'-tetraacetic acid
HEDTA
N-(2-Hydroxyethyl)-ethylenediamine-N,N',N'-triacetic acid
DTPA
Diethylene-triamine-N,N,N',N'',N''-pentaacetic acid
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Activity n°2

13

A2. Researchers must select the extractants and the diluents. According to the information available and the strategy chosen, which extractants and diluents do you select?

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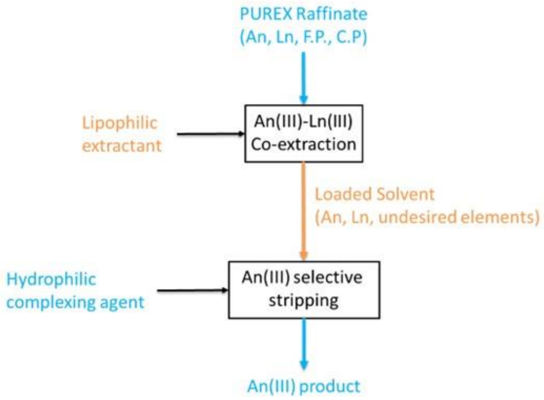
Activity n°2

14

A2. Hints

- Ligand molecular structure to be affine to or selective for…
- CHON principle
-
- Process sections: extraction, scrubbing, stripping



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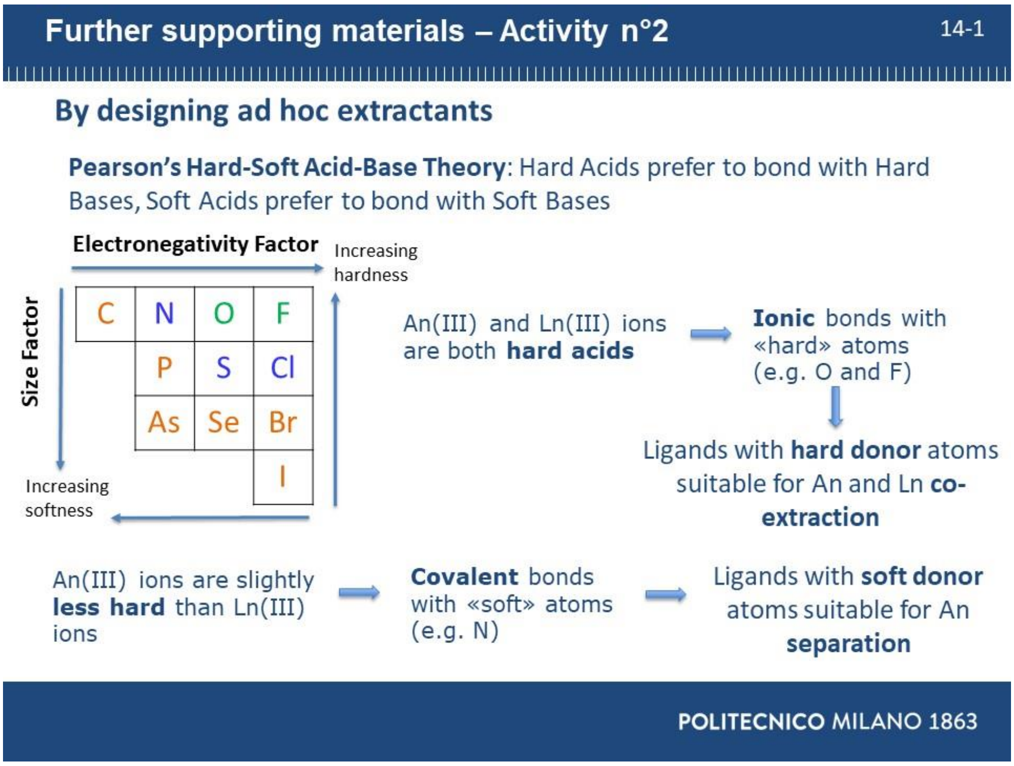
Further supporting materials – Activity n°2
14-1
By designing ad hoc extractants
Pearson's Hard-Soft Acid-Base Theory: Hard Acids prefer to bond with Hard Bases, Soft Acids prefer to bond with Soft Bases
Electronegativity Factor
Increasing hardness
Size Factor
C N O F
P S Cl
As Se Br
I
Increasing softness
An(III) and Ln(III) ions are both hard acids
Ionic bonds with «hard» atoms (e.g. O and F)
Ligands with hard donor atoms suitable for An and Ln co-extraction
An(III) ions are slightly less hard than Ln(III) ions
Covalent bonds with «soft» atoms (e.g. N)
Ligands with soft donor atoms suitable for An separation
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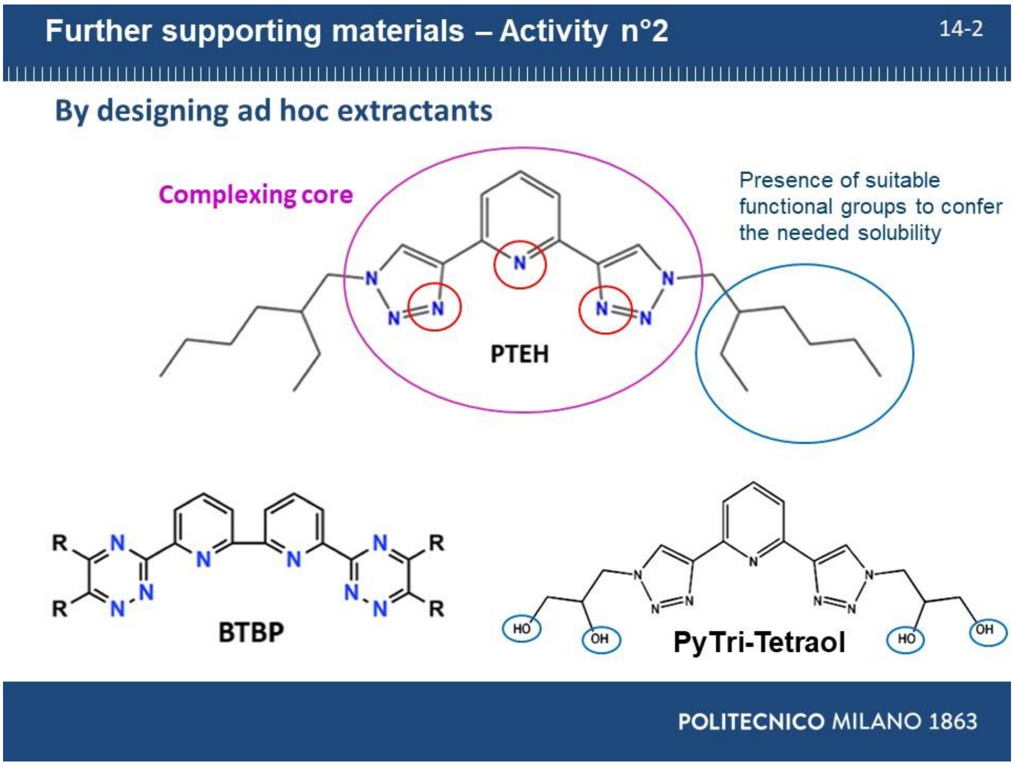
Further supporting materials – Activity n°2
14-2
By designing ad hoc extractants
Complexing core
Presence of suitable functional groups to confer the needed solubility
PTEH
BTBP
PyTri-Tetraol
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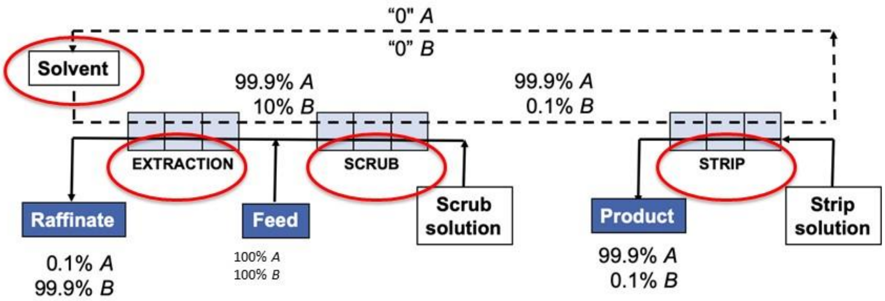
Further supporting materials – Activity n°2

14-3

In reality, to achieve required performance, the process is
- Continuous
- Multi-stage
- Counter-current
- Multi-section



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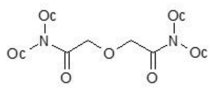
Extraction data

15

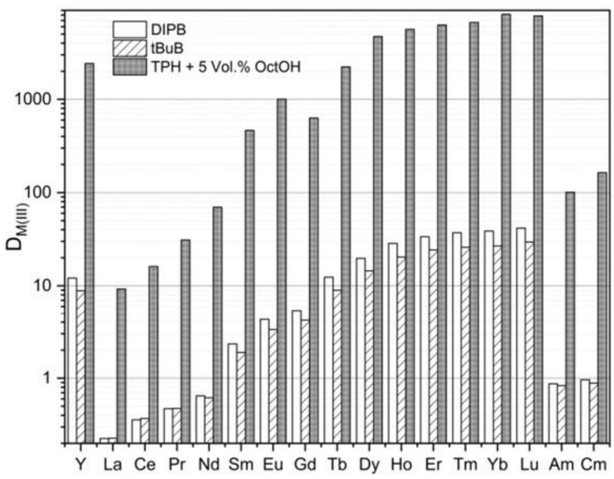
TODGA data:



Org phase: 0.2M TODGA in diluent

Aq phase: 0.5 mol/L HNO_3 solution

Distribution ratio



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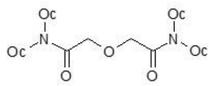
Extraction data

16

TODGA data:



Aq phase: 3.1 mol/L HNO_3 solution

Org phase: 0.2M TODGA in TPH + 5% 1-octanol

Element	Distribution ratios
^{241}Am	>100
^{239}Pu	–
Y	>100
La	88
Ce	>100
Pr	>100
Nd	>100
Sm	>100
Eu	>100
^{152}Eu	>100
Gd	>100
Zr	>100
Pd	4.75
Ag	n.d.
Ba	<0.01
Cd	0.07
Mo	0.24
Ni	<0.01
Sr	1.23
Rb	<0.01
Ru	0.21
Cr, Cu, Sb, Sn, Se, Ce, Cs, Rh, Te, Al, Na	<0.01

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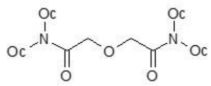
Extraction data

17

TODGA data:



Aq phase: 3 mol/L HNO_3 solution

Org phase: 0.2M TODGA in kerosene + 5% 1-octanol

Elementi	D_{medio}	% in org
Al	3,12	75,74%
Cr	0,016	1,61%
Ni	0,012	1,18%
Cu	0,108	9,73%
Se	0,134	11,81%
Rb	0,001	0,09%
Sr	2,78	73,58%
Y	12766	99,99%
Zr	190	99,48%
Mo	1,19	54,37%
Ru	0,66	39,87%
Rh	0,002	0,24%
Pd	35,37	97,25%
Ag	0,26	20,59%
Cd	0,14	12,50%
Sn	0,06	5,61%
Sb	0,01	1,44%
Te	0,001	0,13%
Cs	0,0001	0,01%
Ba	0,042	4,05%
La	157	99,37%
Ce	661	99,85%
Pr	1800	99,94%
Nd	4681	99,98%
Sm	2101	99,95%
Eu	827	99,88%
Gd	3622	99,97%
^{241}Am	8325	99,99%
^{152}Eu	29547	100,00%

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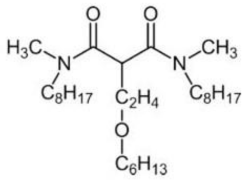
Extraction data

18

DMDOHEMA data:



Organic phase:
0.6 mol/L **DMDOHEMA** in TPH

Aqueous phase:
3.1 mol/L HNO_3

Mixing time: 15 min.;
T = 22 ± 1°C

Element	Distribution ratios
^{241}Am	2.10
^{239}Pu	–
Y	0.32
La	1.69
Ce	2.06
Pr	2.04
Nd	1.77
Sm	1.36
Eu	1.14
^{152}Eu	1.04
Gd	1.32
Zr	104
Pd	3.69
Ag	n.d.
Ba	<0.01
Cd	0.19
Mo	7.71
Ni	<0.01
Sr	<0.01
Rb	0.09
Ru	0.27
Cr, Cu, Sb, Sn, Se, Ce, Cs, Rh, Te, Al, Na	<0.01

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Extraction data

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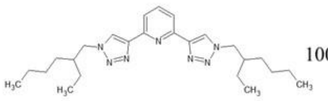
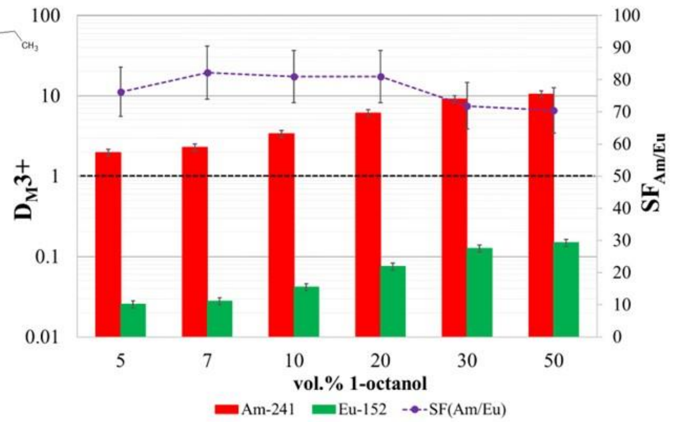
PTEH data:



Organic phase:
0.2M PTEH in kerosene/1-octanol mixtures

Aqueous phase:
3 M HNO_3 spiked with trace amounts of ^{241}Am(III) and ^{152}Eu(III)



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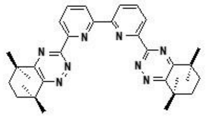
Extraction data
20

CyMe4-BTBP data:



Organic phase: 0.015 mol/L CyMe4BTBP, 0.005 mol/L TODGA in TPH/1-Octanol = 40/60

Aqueous phase: Metal cations in 3.2 M HNO_3 spiked with trace amounts of ^{241}Am(III), ^{244C}m(III) and ^{152}Eu(III)

Element	Concentration [mg/L or as shown]	Distribution ratio
^{241}Am	trace amounts	10.8
^{244}Cm	trace amounts	4.3
Y	90	0.04
La	239	<0.01
Ce	567	<0.01
Pr	223	0.01
Nd	718	0.02
Sm	149	0.07
Eu	34	0.16
^{152}Eu	trace amounts	0.06
Gd	51	0.08
Ni	40	30.0
Cu	19	4.88
Zr	1071	0.50
Mo	678	2.57
Pd	168	6.19
Ag	12	0.88
Cd	15	12.3
Cr	93	0.02
Sn	11	0.12
Sb	4.6	0.12
Rb	63	0.08
Ru	356	0.09
Rh	73	<0.01
Te	165	0.03
Sr	177	<0.01
Ba	259	<0.01
Cs	542	<0.01
Al	2	n.d.
Fe	1900	n.d.
Se	10	n.d.
Na	1600	n.d.
HNO_3	3.2 mol/L	

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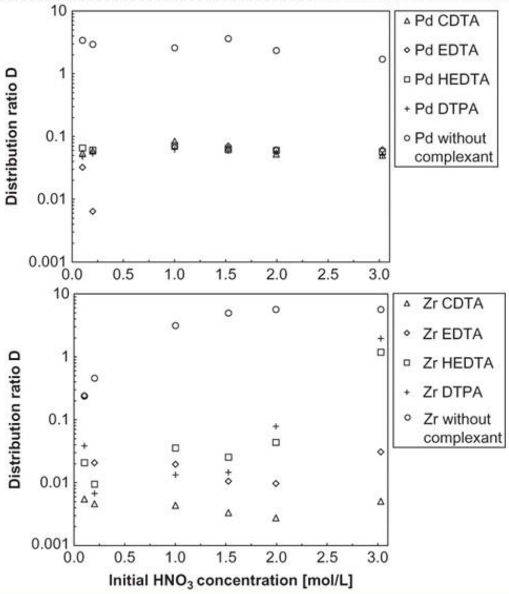
Extraction data
21

Masking agents

Organic phase: 0.2 mol/L **TODGA** + 0.5 mol/L **TBP** in TPH

Aqueous phase: variable HNO3 concentration, 0.1 mol/L complexant concentration,

Mixing time: 15 min.;
T = 22 ± 1°C



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Extraction data

22

Masking agents

Organic phase: 0.2 mol/L **TODGA** in kerosene + 5% 1-octanol

Aqueous phase: 3.1 mol/L HNO_3, 0.05 mol/L CDTA

Mixing time: 15 min.;
T = 22 ± 1°C

Elementi	D	% in org
Al	2,22	68,96%
Cr	0,007	0,65%
Se	0,052	4,93%
Sr	3,10	75,59%
Y	5698	99,98%
Zr	1,50	59,98%
Mo	0,66	39,90%
Ru	0,31	23,76%
Rh	0,011	1,05%
Pd	0,11	9,94%
Ag	1,89	65,41%
Cd	0,118	10,53%
Cs	0,0001	0,01%
Ba	0,0485	4,63%
La	141	99,30%
Ce	491	99,80%
Pr	1138	99,91%
Nd	2156	99,95%
Sm	1547	99,94%
Eu	741	99,87%
Gd	4741	99,98%
^{241}Am	6255	99,98%
^{152}Eu	11231	99,99%

Organic phase: 0.6 mol/L **DMDOHEMA** in TPH

Aqueous phase: 3.1 mol/L HNO_3, 0.05 mol/L CDTA

Mixing time: 15 min.;
T = 22 ± 1°C

Element	Without complexant	CDTA
^{241}Am	2.10	2.65
^{239}Pu	–	–
Y	0.32	0.40
La	1.69	2.13
Ce	2.06	2.62
Pr	2.04	2.52
Nd	1.77	2.16
Sm	1.36	1.67
Eu	1.14	1.39
^{152}Eu	1.04	1.27
Gd	1.32	1.84
Zr	104	0.01
Pd	3.69	0.03
Ag	n.d.	n.d.
Ba	<0.01	<0.01
Cd	0.19	0.08
Mo	7.71	2.07
Ni	<0.01	<0.01
Sr	<0.01	<0.01
Rb	0.09	0.09
Ru	0.27	0.28
Cr, Cu, Sb, Sn, Se, Ce, Cs, Rh, Te, Al, Na	<0.01	<0.01

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Activity n°3

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A3. Researchers must select the composition of the organic and aqueous phases in the extraction section of the process. According to the data available, which concentrations for the extractants and nitric acid do you propose for the <u>extraction section</u>?

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Activity n°3

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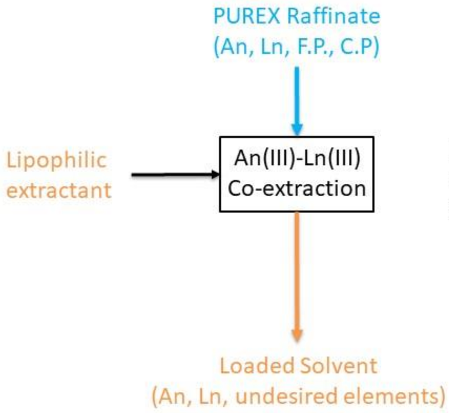
A3. Hints



$D_{An} = [M]_{org}/[M]_{aq} >> 1$
$D_{Ln} = [M]_{org}/[M]_{aq} >> 1$
$SF_{An/Ln} = D_{An} / D_{Ln} \approx 1$

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Loaded organic solvent - characteristics

25

Loaded organic solvent:

consists of TODGA in kerosene + 5% 1-octanol

and contains:

- Am, Cm, Lns: target elements
- Sr, Zr, etc: undesired co-extracted elements
- HNO_3: co-extracted by 1-octanol and TODGA during extraction section, $[HNO_3]_{org} \approx 0.2$ mol/L (extraction at 3M HNO_3)

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Nitric acid extraction data

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EXTRACTION OF NITRIC ACID

by the extractant due to **Protonation**

by the diluent, in this case 1-octanol:

$$n\,\mathrm{H}^+ + n\,\mathrm{NO}_3^- + p\,\mathrm{ROH} \rightleftharpoons (\mathrm{HNO}_3)_n(\mathrm{ROH})_p$$

Changes in acidity at equilibrium of aq phase

Changes in D values

Org. phase:	Aq. phase: $[HNO_3]_{aq,\,init}$ (M)	$[HNO_3]_{realised}$ from org to aq	Aq. Phase after: $[HNO_3]_{aq,\,eq}$ (M)
loaded with metal cations (feed at 3M HNO_3)	0,1011	0,2063	0,3074
	0,2072	0,2036	0,4109
	0,2521	0,2007	0,4529
	0,5051	0,1878	0,6928
	1,0175	0,1242	1,1416
	2,0264	0,0504	2,0769
	2,9692	0,0107	2,9799

Changes in acidity of aq phase

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Extraction data

27

Org. phase: loaded with metal cations from Extraction section

Aq. phase: 0.5 mol/L HNO_3 solution

Elementi	D	% in acq
Al	8,33	10,72%
Sr	0,17	85,21%
Y	1242	0,08%
Zr	72	1,37%
Ag	22,47	4,26%
La	4,2	19,11%
Ce	7,4	11,91%
Pr	14	6,85%
Nd	27	3,51%
Sm	165	0,60%
Eu	328	0,30%
Gd	77	1,27%
^{241}Am	55	1,77%
^{152}Eu	426	0,23%

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Activity n°4

28

A4. Researchers must select the composition of the aqueous phase in the <u>scrubbing</u> section of the process.
Based on the available data, is it necessary to add the scrubbing section? If so, which aqueous phase do you propose to use for the <u>scrubbing section</u>?

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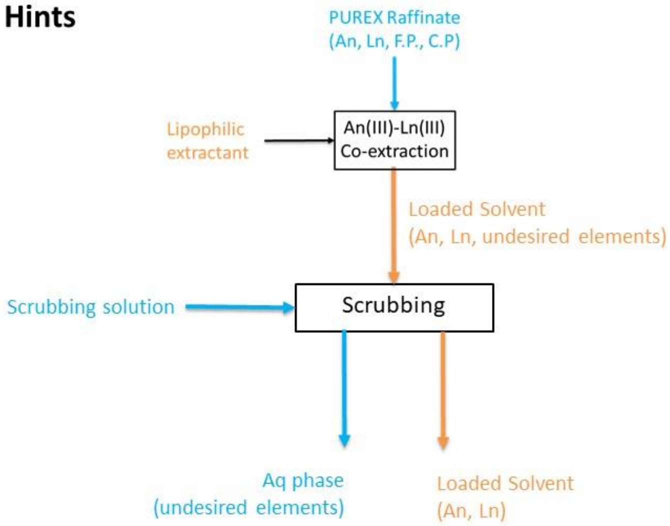
Activity n°4

29

A4. Hints



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Loaded and scrubbed organic solvent - characteristics

30

Loaded organic solvent:

consists of TODGA in kerosene + 5% 1-octanol

and contains:

- Am, Cm, Lns: target elements
- Sr, Zr, etc: undesired co-extracted elements
- HNO_3: co-extracted by 1-octanol and TODGA during extraction section, $[HNO_3]_{org} \approx 0.2$ mol/L (extraction at 3M HNO_3)

↓

Loaded and scrubbed organic solvent:

contains:

- Am, Cm, Lns: target elements

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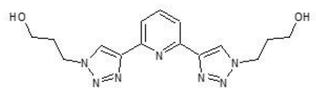
Extraction data

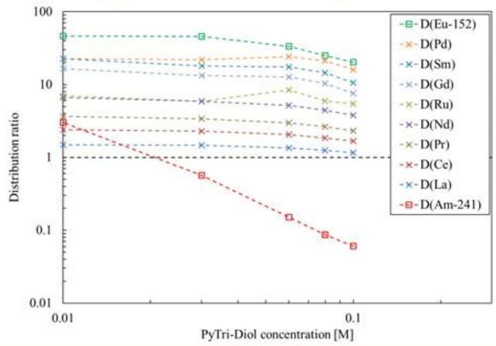
31

PyTri-Diol data:



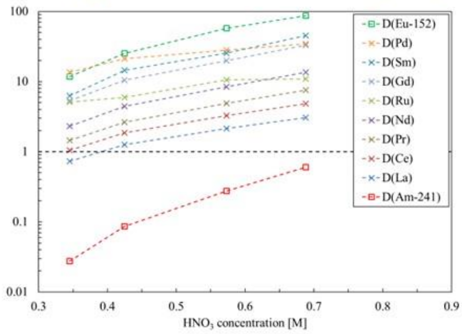
Org. phase: loaded with metal cations

Aq. phase: PTD in 0.4M HNO_3



Org. phase: loaded with metal cations

Aq. phase: 0.08 M PTD in **different $[HNO_3]$**



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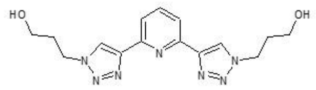
Extraction data

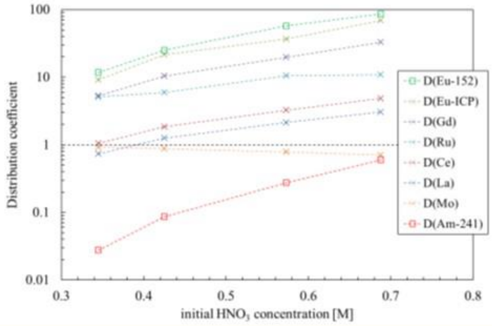
32

PyTri-Diol data:



Org. phase: loaded with metal cations

Aq. phase: 0.08 M PTD in **different [HNO_3]**



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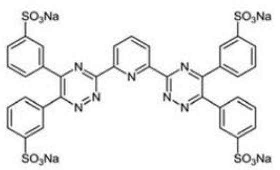
Extraction data

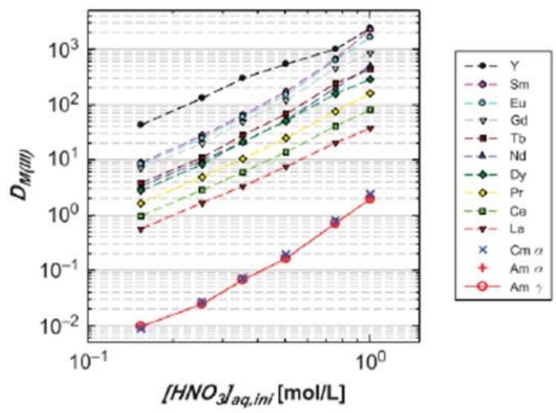
33

SO_3-Ph-BTP data:



Org. phase: loaded with metal cations

Aq. phase: 18 mmol/L SO_3-Ph-BTBP in HNO_3



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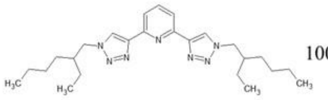
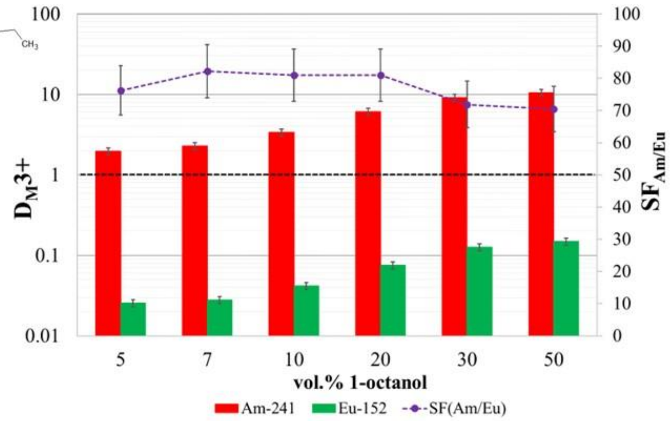
Extraction data

34

PTEH data:





Organic phase:
0.2M PTEH in kerosene/1-octanol mixtures

Aqueous phase:
3 M HNO_3 spiked with trace amounts of ^{241}Am(III) and ^{152}Eu(III)

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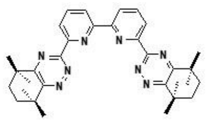
Extraction data

35

CyMe4-BTBP data:



Organic phase:
0.015 mol/L CyMe4BTBP, 0.005 mol/L TODGA in TPH/1-Octanol = 40/60

Aqueous phase:
Metal cations in 3.2 M HNO_3 spiked with trace amounts of ^{241}Am(III), ^{244C}m(III) and ^{152}Eu(III)

Element	Concentration [mg/L or as shown]	Distribution ratio
^{241}Am	trace amounts	10.8
^{244}Cm	trace amounts	4.3
Y	90	0.04
La	239	<0.01
Ce	567	<0.01
Pr	223	0.01
Nd	718	0.02
Sm	149	0.07
Eu	34	0.16
^{152}Eu	trace amounts	0.06
Gd	51	0.08
Ni	40	30.0
Cu	19	4.88
Zr	1071	0.50
Mo	678	2.57
Pd	168	6.19
Ag	12	0.88
Cd	15	12.3
Cr	93	0.02
Sn	11	0.12
Sb	4.6	0.12
Rb	63	0.08
Ru	356	0.09
Rh	73	<0.01
Te	165	0.03
Sr	177	<0.01
Ba	259	<0.01
Cs	542	<0.01
Al	2	n.d.
Fe	1900	n.d.
Se	10	n.d.
Na	1600	n.d.
HNO_3	3.2 mol/L	

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Activity n°5

36

A5. Researchers must select the composition of the aqueous phase in the stripping section of the process.
Based on the available data, is it necessary to use a complexing agent? If so, which one and at what concentration do you propose to use for the stripping section?

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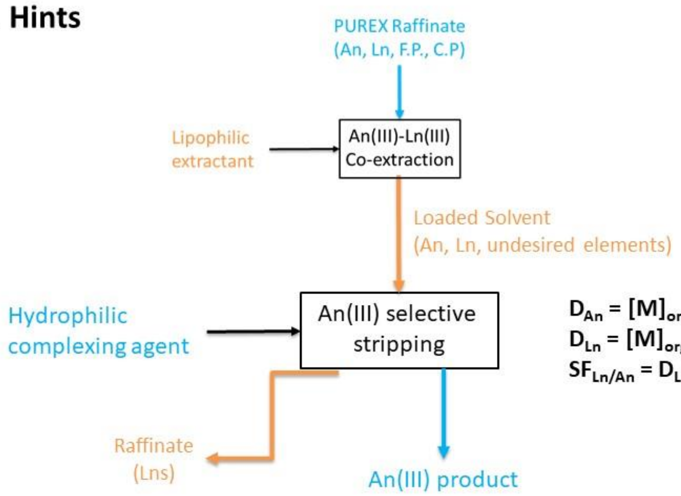
Activity n°5

37

A5. Hints



$D_{An} = [M]_{org}/[M]_{aq} << 1$

$D_{Ln} = [M]_{org}/[M]_{aq} >> 1$

$SF_{Ln/An} = D_{Ln} / D_{An} >> 1$

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Additional extraction data

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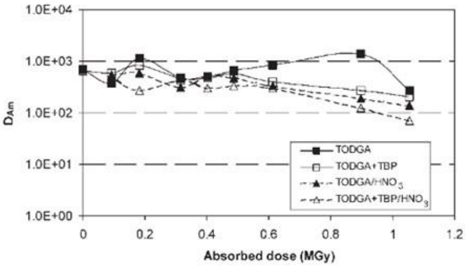
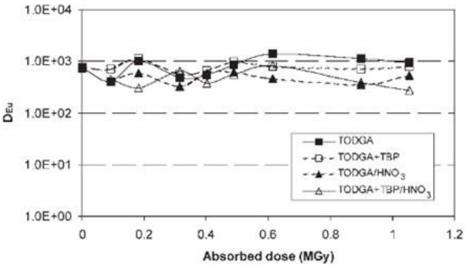
TODGA data:

Org. phase:irradiated 0.2 M TODGA in TPH

Aq. phase: 3 M HNO_3





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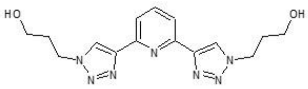
Additional extraction data

39

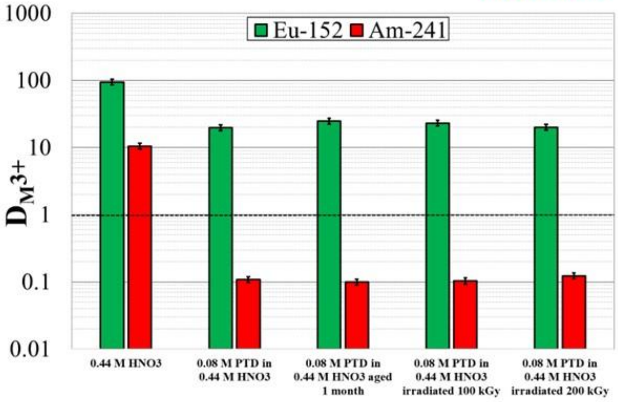
PyTri-Diol data:



Metal loading experiment

Org. phase: 0.2 M TODGA in kerosene + 5 vol.% 1-octanol loaded from 3 M HNO_3 feed containing 1.8 g/L of Y and Ln (La – Gd), **0.001 M ^{241}Am(III)** and ^{152}Eu as tracer

Aq. phase: fresh, **aged** and **irradiated**



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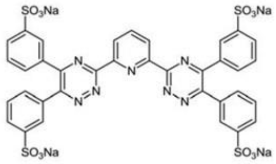
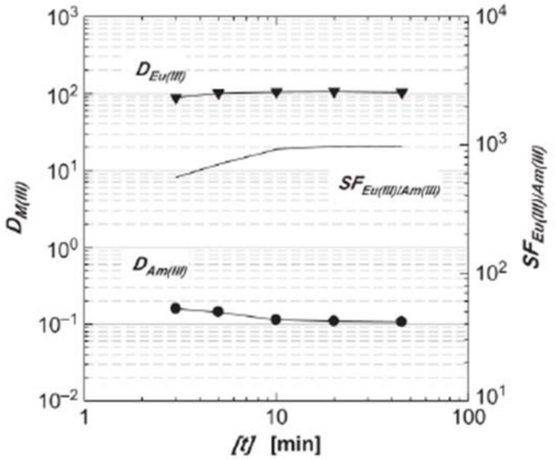
Additional extraction data

40

SO_3-Ph-BTP data:





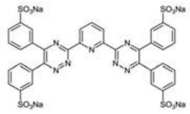
Org. phase: loaded with metal cations

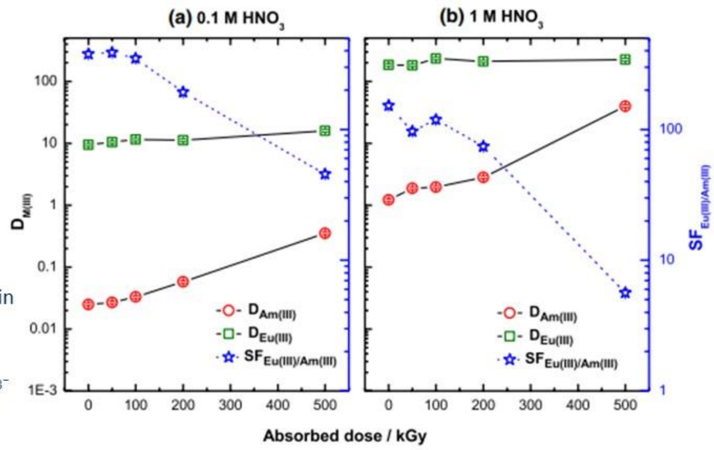
Aq. phase: 18 mmol/L SO_3-Ph-BTBP in 0.29 mol/L HNO_3

Additional extraction data

41

SO_3-Ph-BTP data:





Org. phase: 0.2M TODGA in TPH + 5% 1-octanol

Aq. phase: 20 mmol/L SO_3-Ph-BTBP in 0.1 or 1 mol/L HNO_3

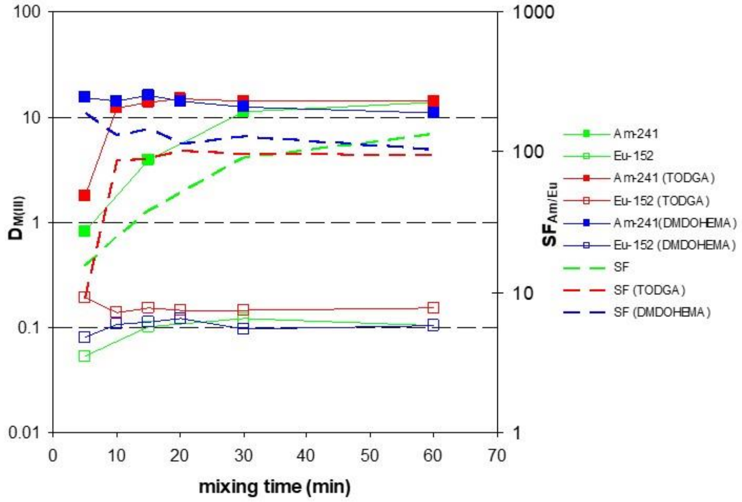
Additional extraction data

42

$CyMe_4$-BTBP data:

Org. phase: 0.015 mol/L CyMe4-BTBP (+ 0.005 mol/L TODGA or 0.25 mol/L DMDOHEMA) in 1-octanol

Aq. phase: ^{241}Am and ^{152}Eu in 1 mol/L HNO_3



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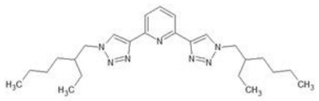
Additional extraction data

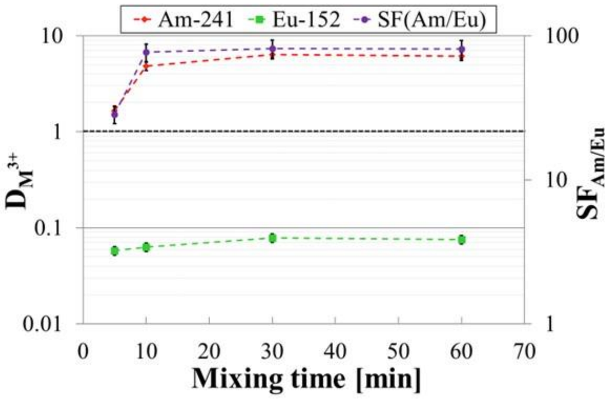
43

PTEH data:



Org. phase: 0.2 mol/L PTEH in kerosene + 10% 1-octanol

Aq. phase: ^{241}Am and ^{152}Eu in 3 mol/L HNO_3



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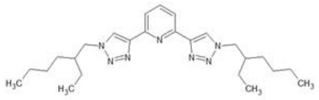
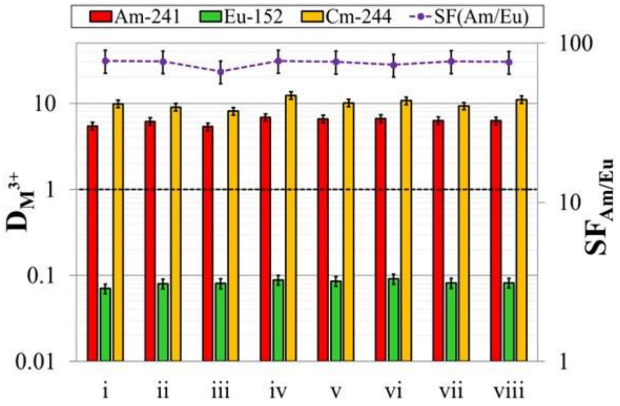
Additional extraction data 44

PTEH data:





Org ph.: 0.2 M PTEH in kerosene + 10 vol.% 1-octanol

Aq ph.: 3 M HNO_3 spiked with trace amounts of trivalent ^{241}Am, ^{244}Cm and ^{152}Eu

i: fresh org phase

ii: org phase **aged** for **71** days

iii: org phase aged in contact with 3 M HNO_3 for **71** days in the dark at T_{amb}

iv, v, vi: org ph **irradiated** at **100, 200** and **300 kGy**, respectively (^{60}Co source, 2.5 kGy/h)

vii, viii: org ph irradiated at **100, 200 kGy** (^{60}Co source, 2.5 kGy/h) in contact with 3 M HNO_3

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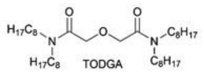
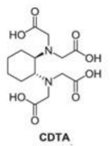
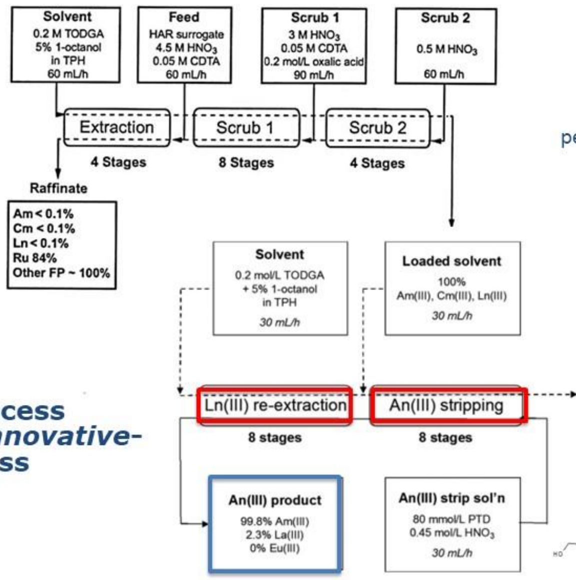
First possible solution from literature 45

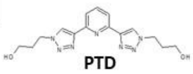






Extraction data

Calculations were performed using the **SX Process code**.



One-step process approach: *innovative*-SANEX process

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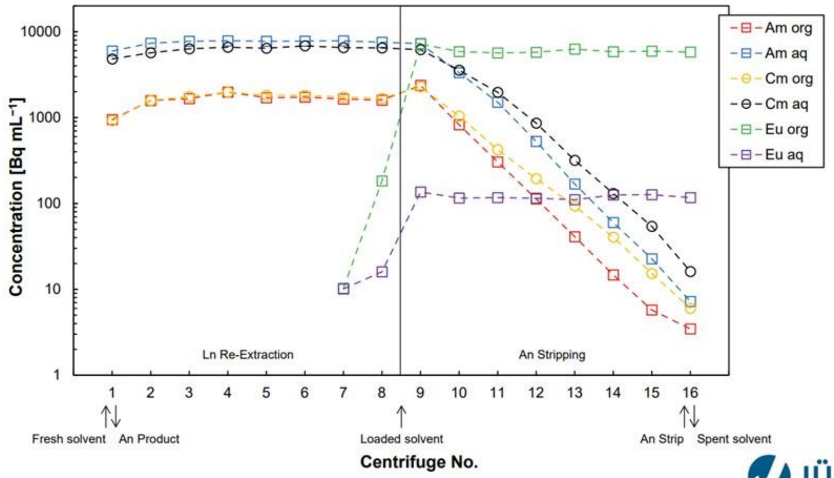
First possible solution from literature

47

i-SANEX experiment in centrifugal contactors battery performed in 2020



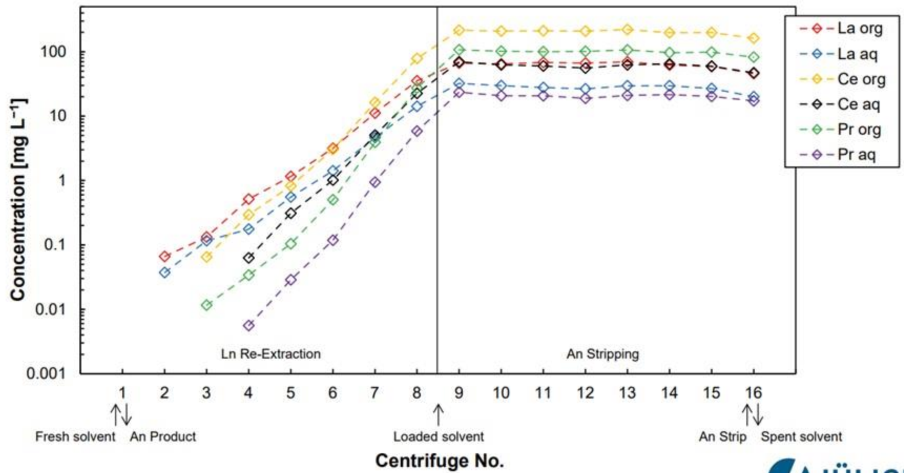
Data related to *Stripping section* and subsequent *Ln back-extraction*

POLITECNICO MILANO 1863

First possible solution from literature

48

i-SANEX experiment in centrifugal contactors battery performed in 2020



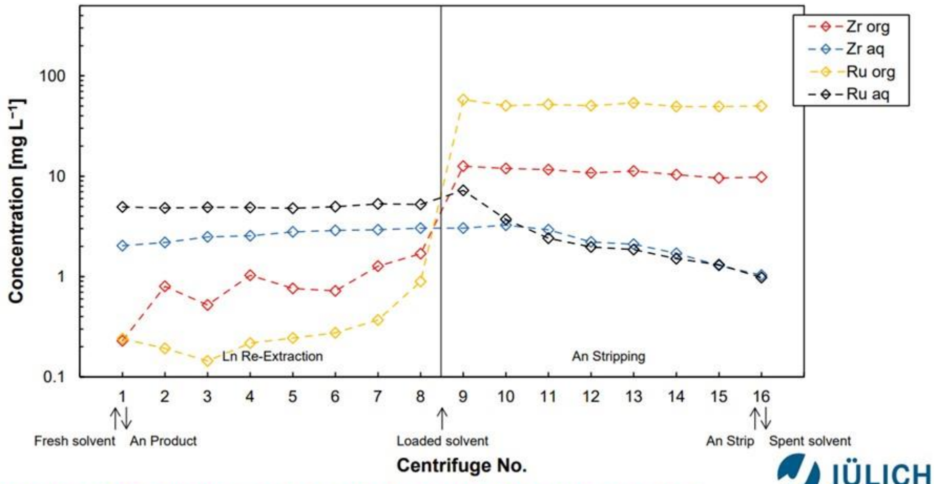
Data related to *Stripping section* and subsequent *Ln back-extraction*

POLITECNICO MILANO 1863

First possible solution from literature

49

i-SANEX experiment in centrifugal contactors battery performed in 2020



Data related to *Stripping section* and subsequent *Ln back-extraction*

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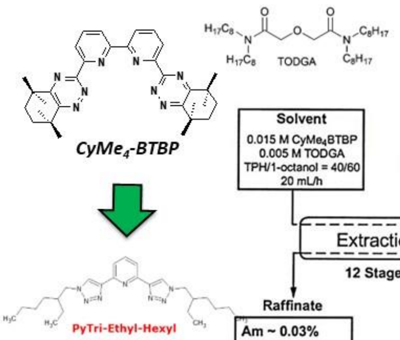
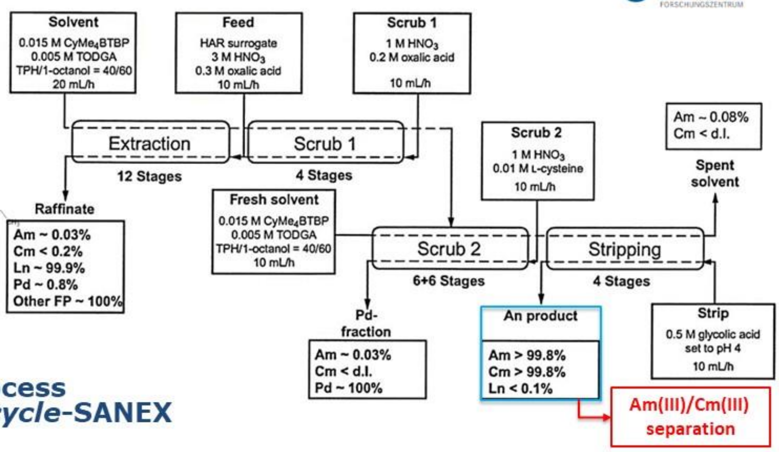
Second possible solution from literature

50



Flowsheet from spiked test carried out at FZJ (Wilden, 2013)



One-step process approach: *1cycle*-SANEX process

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