

Development of separation and purification methods for the quantification of DTM radionuclides in activated steel

PhD Hours : 12/02/2026

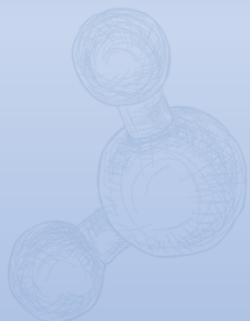
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Management of radioactive waste from nuclear decommissioning



Rubble



Tools



gloves

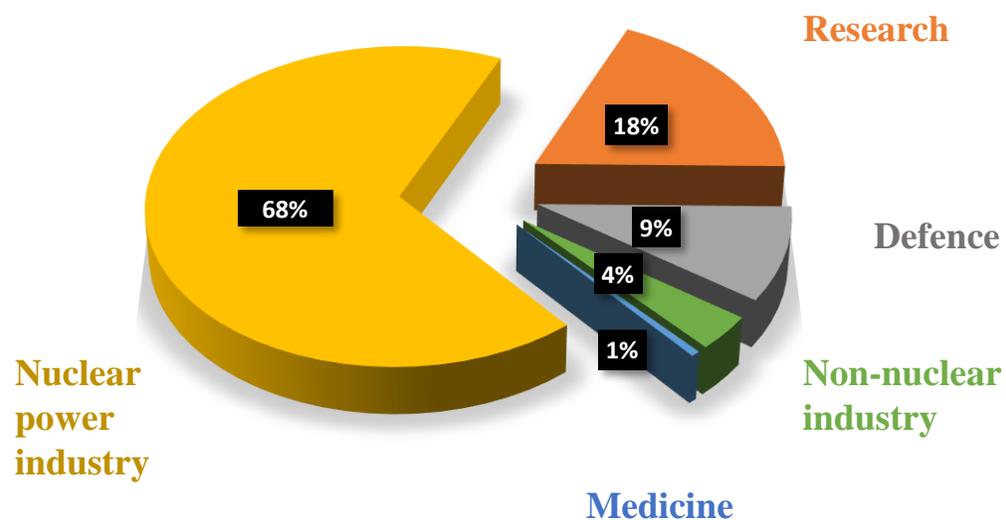


used fuel



used equipment

Distribution of radioactive waste at the end of 2022 *



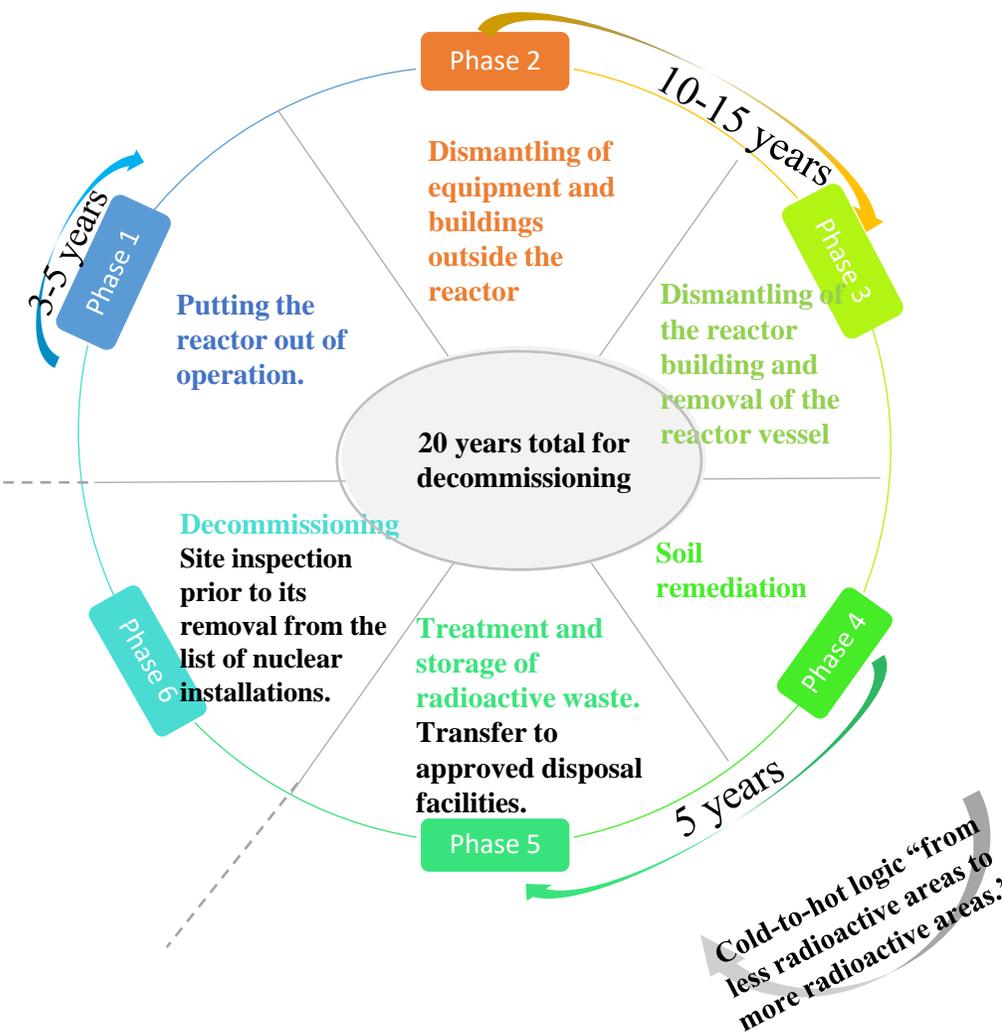
Radioactive waste from the nuclear power industry is generated by :

- Front-end and back-end of fuel cycle
- Maintenance of nuclear facilities
- Dismantling of nuclear installations



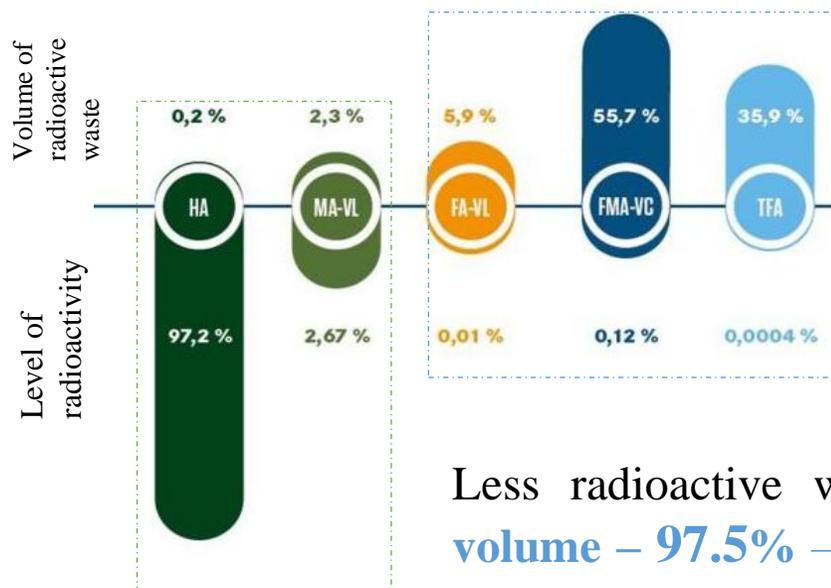
Decommissioning of a nuclear power plant

This includes operations to remove radioactive materials and waste, remove existing equipment, clean up and dismantle the buildings of a nuclear facility at the end of its life or when it is permanently shut down.[1]



Distribution of volume and radioactivity levels of waste stocks at the end of 2021[2]

The most radioactive waste accounts for **~2.5%** of the total **volume**, but contains more than **99.5%** of the **HLW and ILW**.



Less radioactive waste accounts for **the largest volume – 97.5%** – but contains less than **0.5% of LLW, L-ILW, VLLW**



Nuclear reactor under dismantling

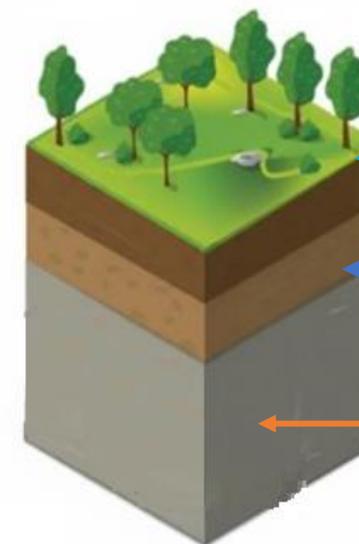
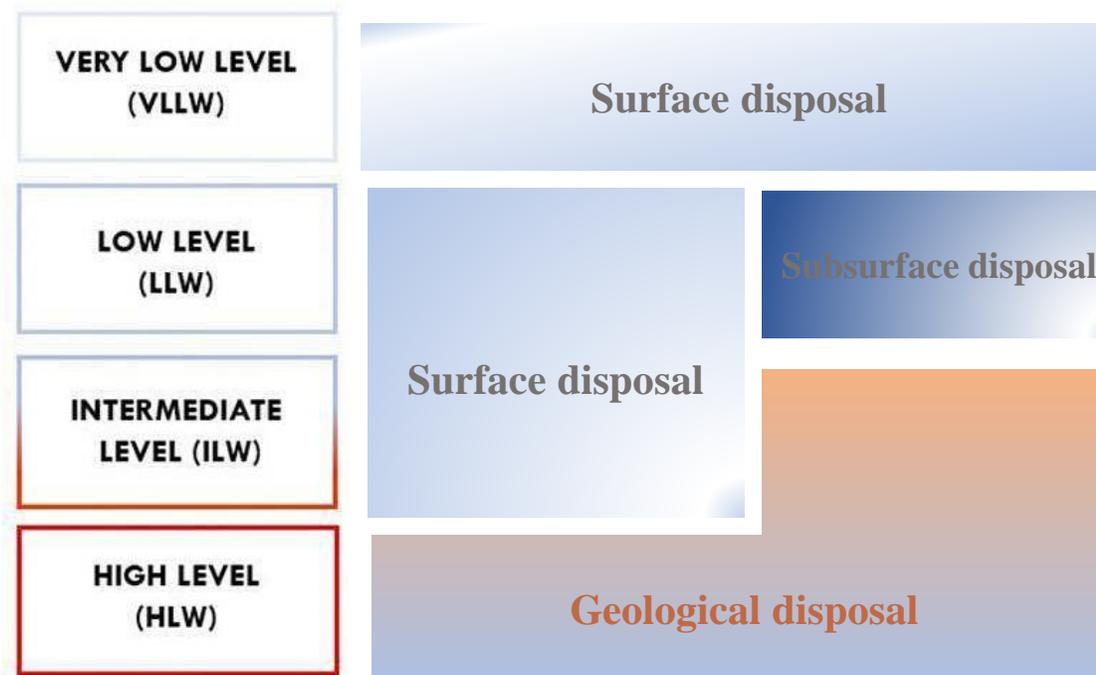
Characterization and classification of waste

- ✓ Composition and activity of the waste
- ✓ Safe management
- ✓ Disposal facilities



Radioactive waste conditioning

SHORT LIVED WASTE (SL) PERIOD \leq 31 years	LONG LIVED WASTE (LL) PERIOD \geq 31 years
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Surface disposal: from ground level to a few meters

Subsurface disposal: from several tens to several hundred of meters

Geological disposal: ~300 to 1000 meters underground

Solids

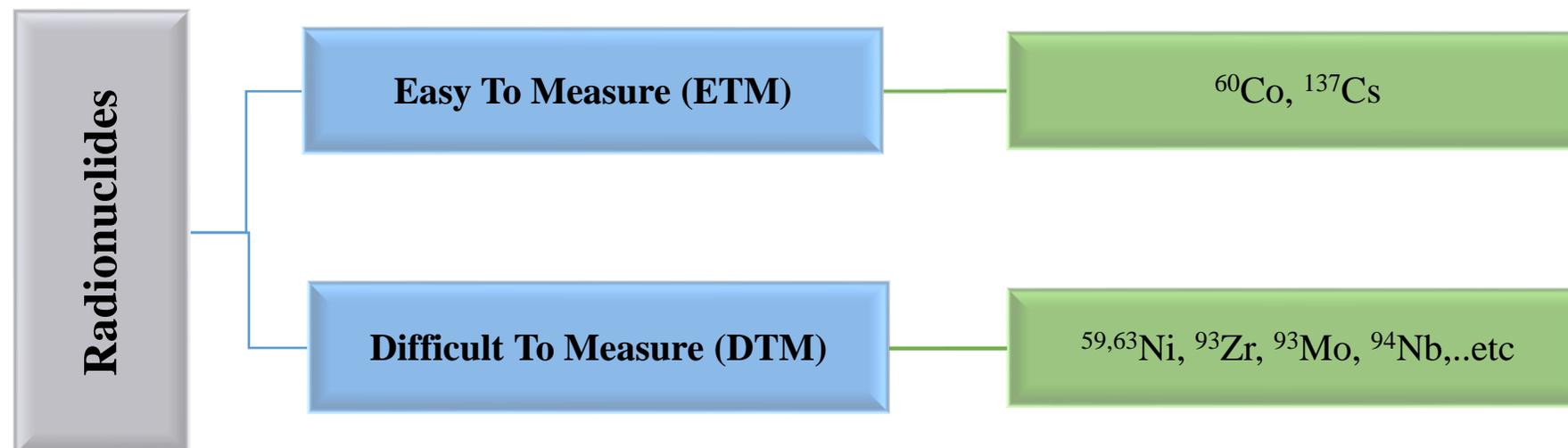
- Dismantling (Concrete, **Steel**, etc.)
- Resins
- Spent fuel

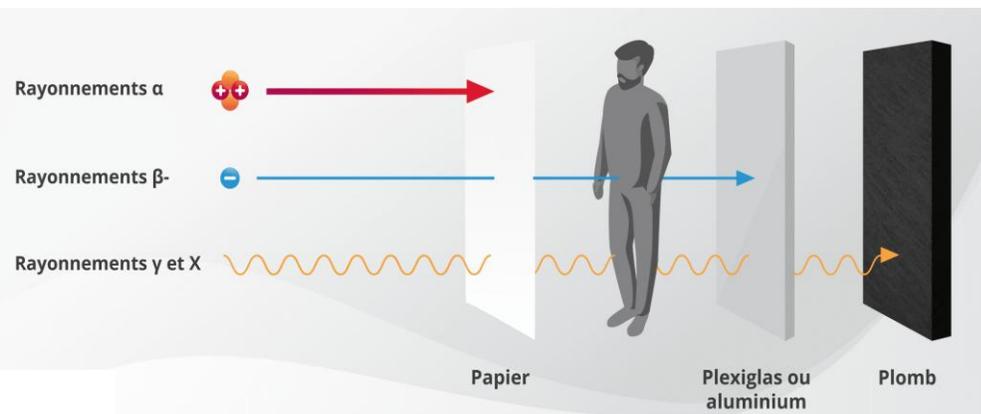
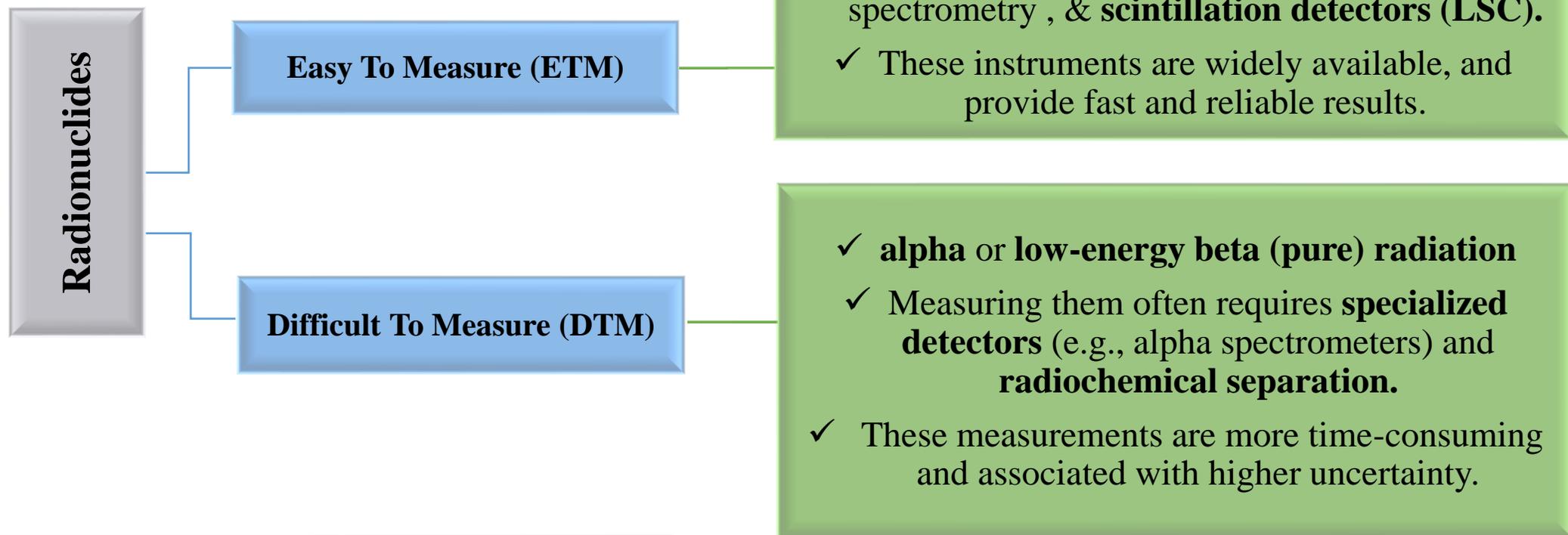
Liquids

- Aqueous effluents
- Radioactives sludge

Gaseous

- Aerosol
- Gaseous tritium



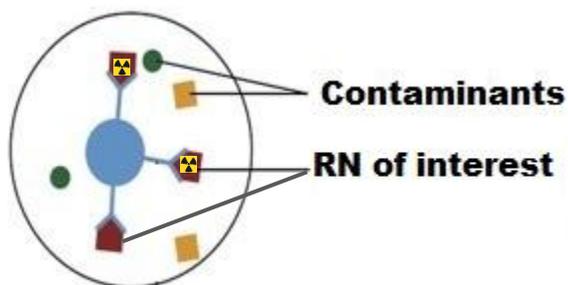
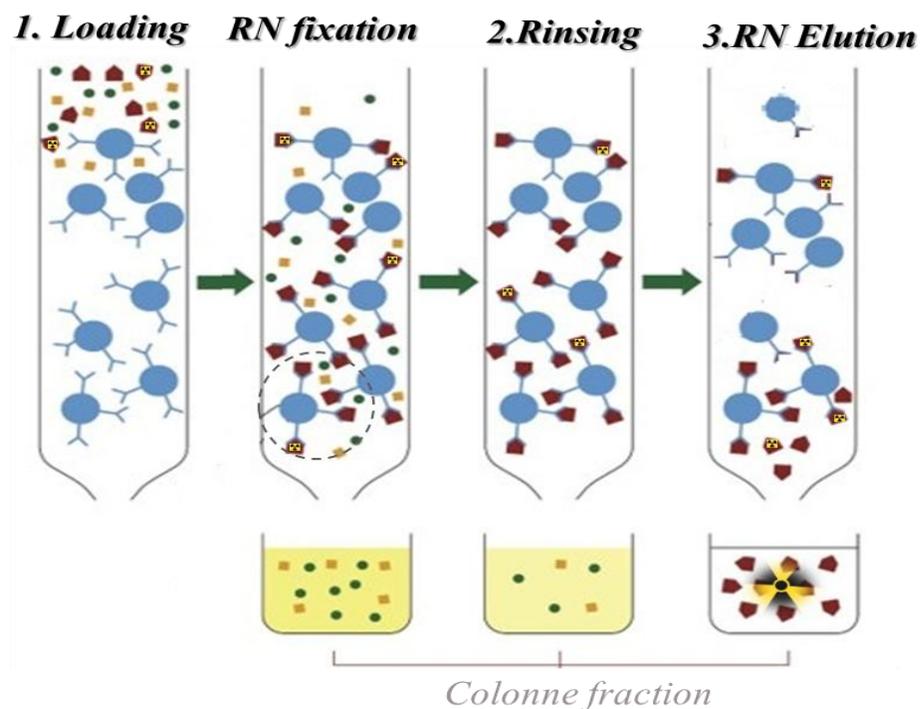


✓ **Radiochemical separation:**

- **Isolate the radionuclide of interest**
- **Remove interferences**
- **Increase measurement sensitivity**

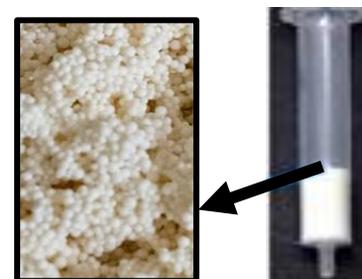
When radiation is weak, non-penetrating, or masked by other RN.

Resin extraction chromatography



Separation method based on the difference in chemical affinity between the species in a solution and a solid phase

The resin consists of **polymer beads**
→ Solid support



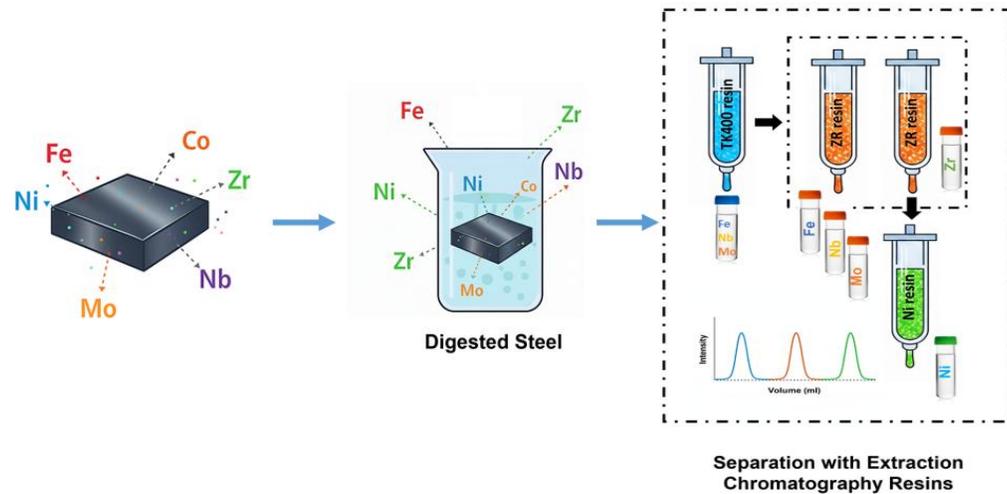
A **ligand molecule** with **specific affinity** for a **target RN** is attached to the beads.



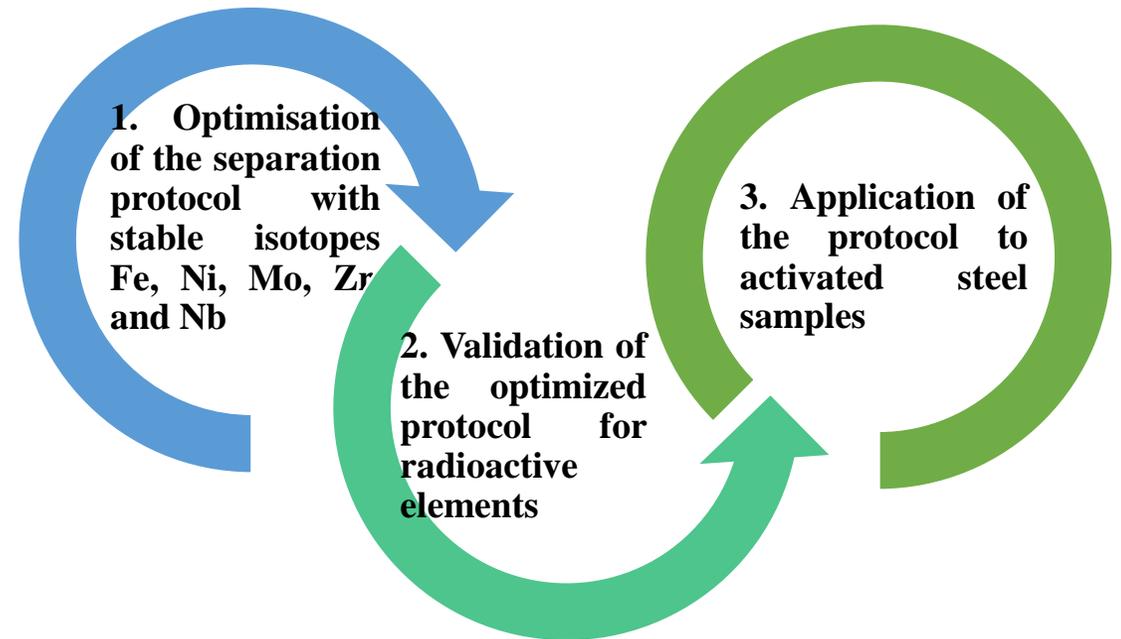
- **1. Loading :** The solution containing the RN is passed through the resin column. → **Target RN** are captured by **the ligand**.
- **2. Rinsing :** A suitable solution is used to **remove** impurities, which have no affinity for **the ligand** , without **eluting the target RN**.
- **3. Elution (Extraction) :** To recover the **target RN**, a **liquid extractant** or **eluent** is used. This liquid **breaks the RN-ligand interaction**.

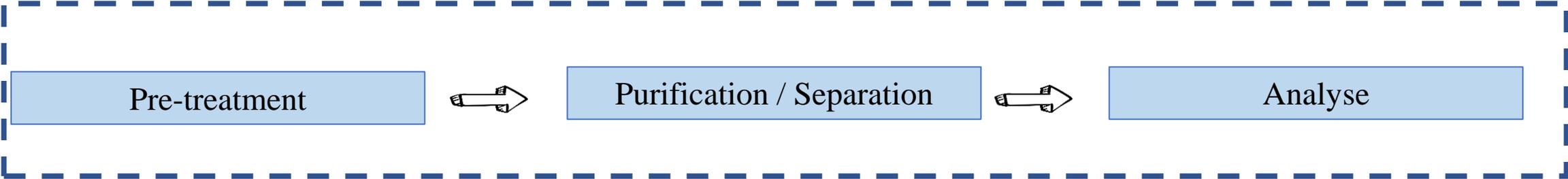


Optimisation of a protocol for the separation of DTM radionuclides such as ^{55}Fe , $^{59,63}\text{Ni}$, ^{93}Zr , ^{93}Mo and ^{94}Nb , in activated steel

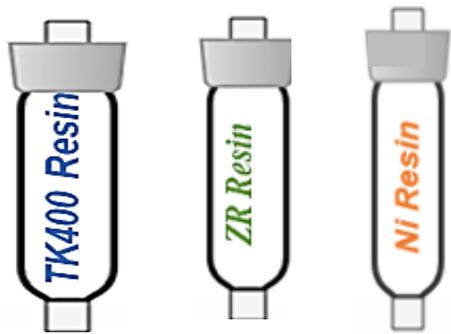


Methodology of work





1. Choice of resins



1. Distribution coefficient

2. Capacity test

3. Elution test

4. Separation test



Criteria for the selection of extraction chromatographic resins

□ Selectivity

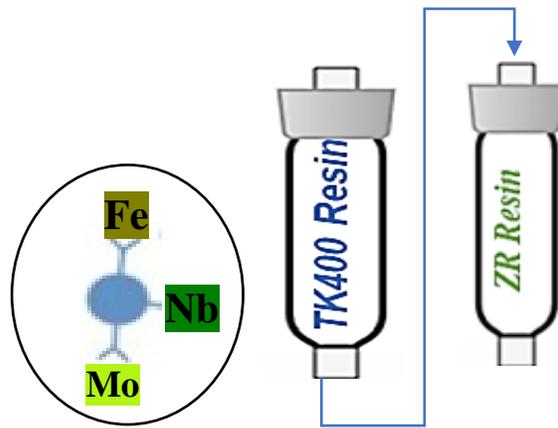
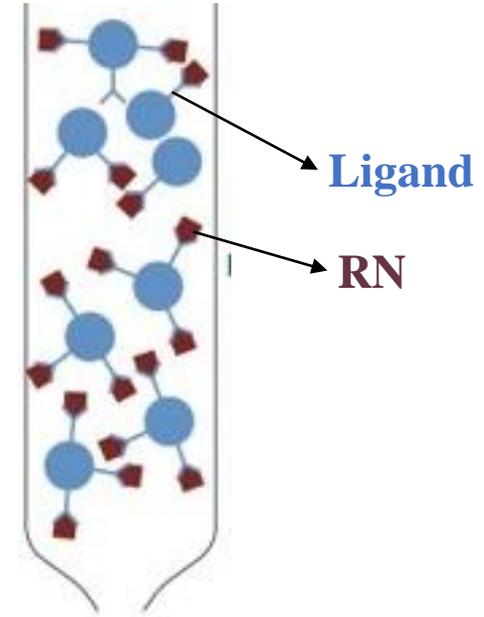
The **chemical affinity between the ligand immobilized on the resin and the target radionuclide**
A highly selective resin minimizes co-retention of interfering radionuclides.

□ Capacity

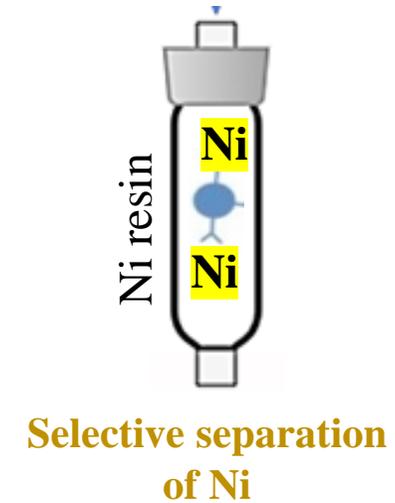
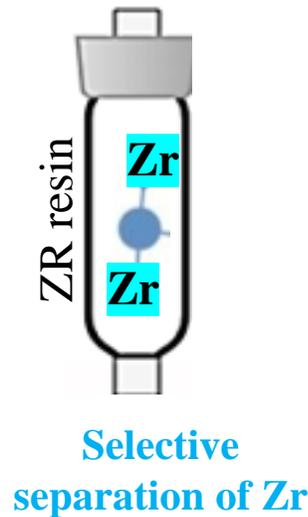
The **maximum amount of radionuclide (RN) that can be retained per gram of resin**.
Higher radionuclide load → higher resin capacity required

□ Specificity

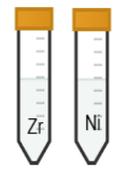
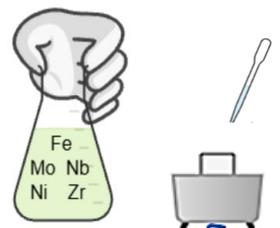
The ability of a resin to **discriminate between chemically similar radionuclides**



Selective separation of Fe, Nb and Mo

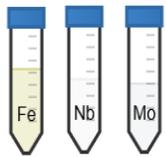


➤ **TK400 Resin:** Separation of Fe, Mo, and Nb from Zr and Ni.



➤ **ZR Resin:** Separation of Zr from Ni.

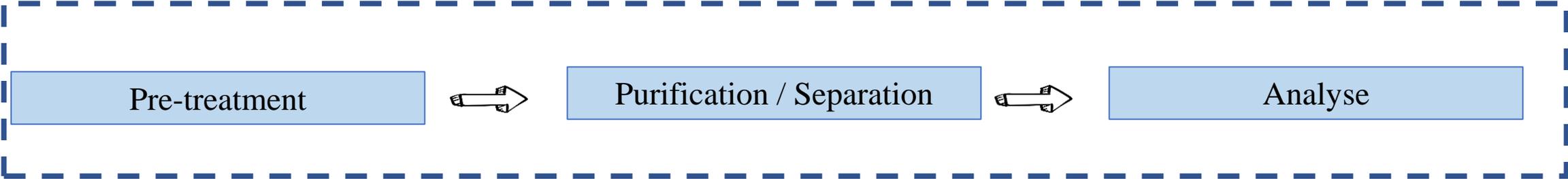
➤ **ZR Résine :** Separate Fe, Nb, and Mo from each other



➤ **Ni Resin:** Purification of Ni



Separation protocol for Fe, Mo, Nb, Zr, and Ni



1. Choice of resins



1. Distribution coefficient

2. Capacity test

3. Elution test

4. Separation test



1. Distribution coefficient D_w

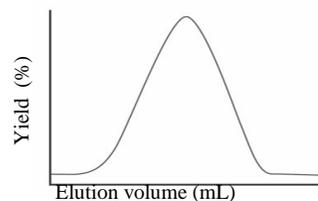
Assess the affinity of a target element for the resin
 → Measure retention/elution efficiency

- Particle size
- Nature of the solvent
- Flow rate
- Concentration of the solvent
- Nature of the adsorbent (stationary phase)
 → Resin)

$$D_w = \frac{(C_i - C_f) \cdot V}{C_f \cdot m}$$

3. Elution test

Assess the effectiveness of desorption by following the elution volume and recovery yield of the element.



Purification / Separation

1. Distribution coefficient



2. Capacity test



3. Elution test

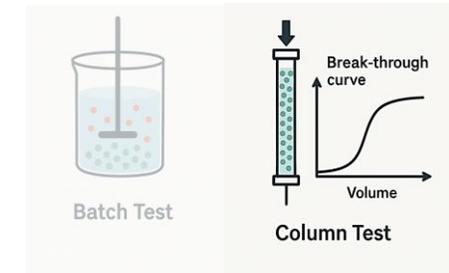


4. Separation test

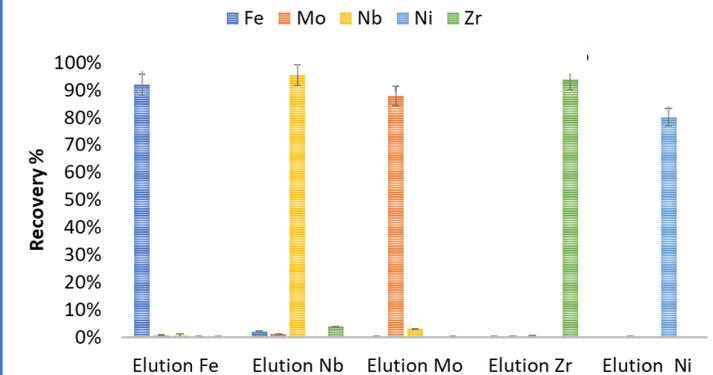
2. Capacity Test

Evaluate the maximum adsorption capacity of a target element by a specific mass of resin before saturation.

- Ligand density
- Porosity / Particle size



4. Separation test

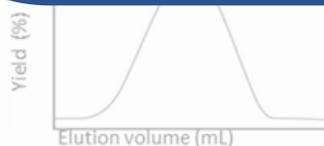


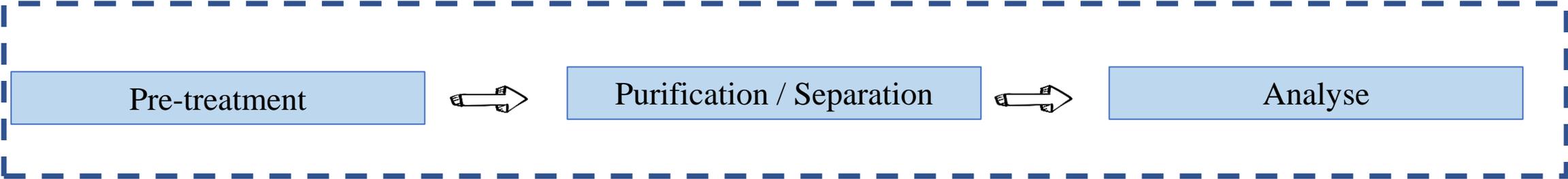
1. Distribution coefficient D_w

Assess the affinity of a target element for the resin
→ Measure

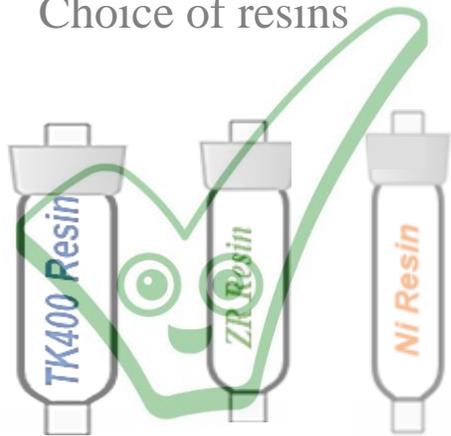
2. Capacity Test

- 1. Distribution coefficient D_w** → Affinity element/resin under given physicochemical conditions, such as concentration and nature of solvent
- 2. Capacity test** → Adsorption capacity (mg/g or mmol/g)
- 3. Elution test** → Eluent volume / Recovery efficiency
- 4. Separation test:** Evaluate the selectivity of the resin





1. Choice of resins

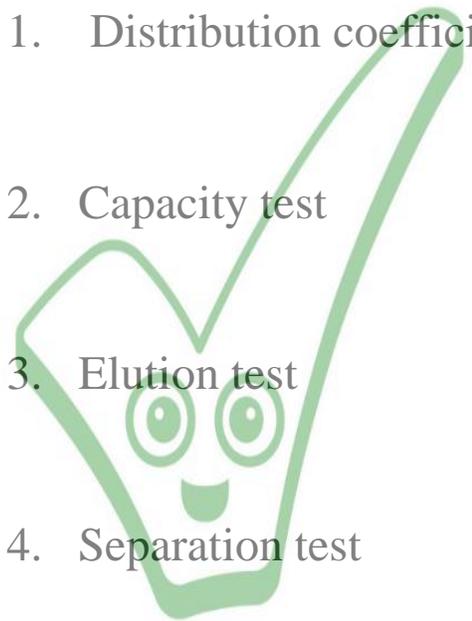


1. Distribution coefficient

2. Capacity test

3. Elution test

4. Separation test



ICP-MS-TQ



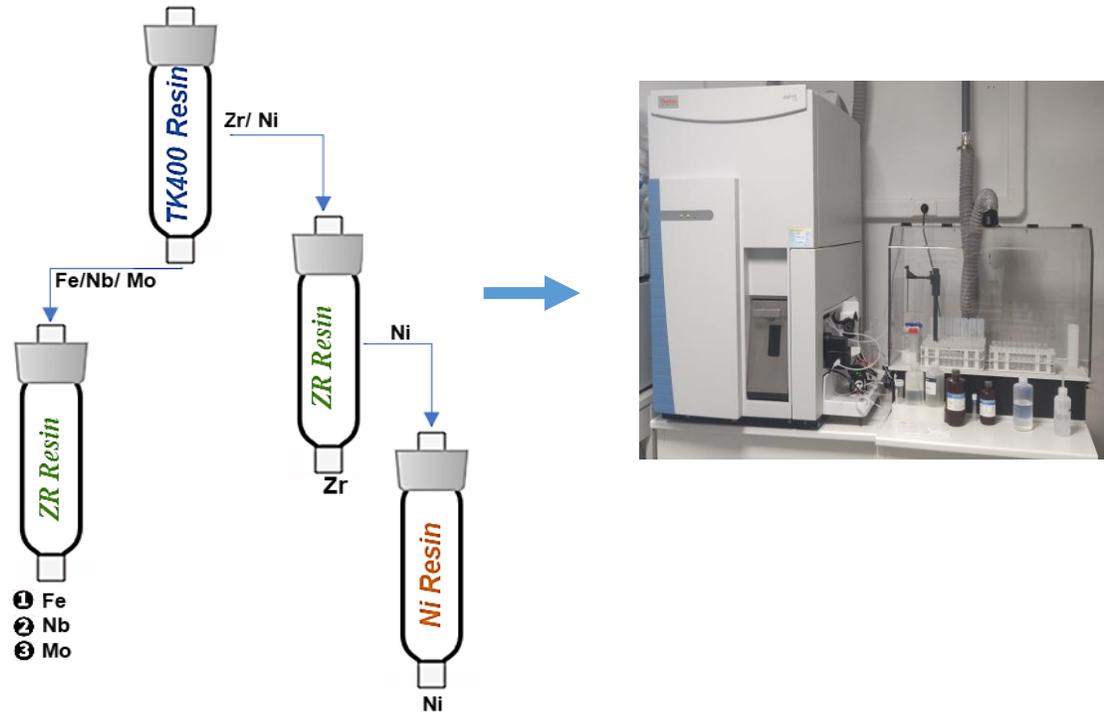
LSC



LEGe detector



The protocol is applied under different conditions for the target elements, varying their concentrations

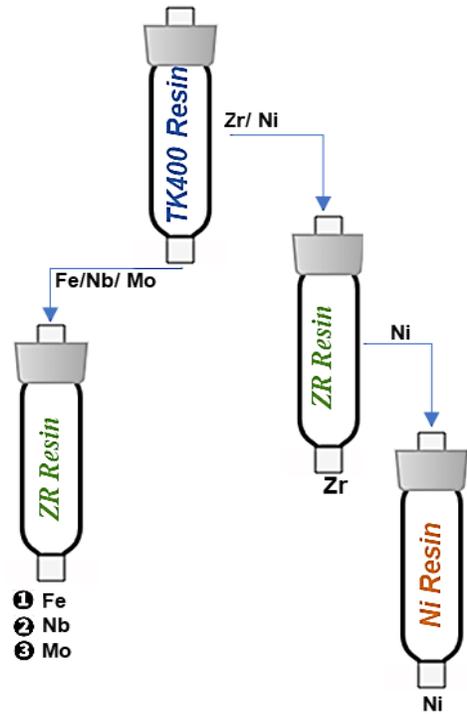


Sequential separation of Fe, Mo, Nb, Ni, and Zr elements



Elements	Yields
Fe	$85 \pm 5\%$ to $92 \pm 4\%$
Mo	$76 \pm 4\%$ to $95 \pm 4\%$
Nb	$88 \pm 4\%$ to $91 \pm 6\%$
Zr	$75 \pm 4\%$ to $94 \pm 4\%$
Ni	$80 \pm 4\%$ to $90 \pm 4\%$

→ Robustness and reliability of the protocol



Separation for ^{55}Fe & ^{63}Ni



RN	Yields
^{55}Fe	LSC → 75 % ± 6
	LEGe → 86 % ± 4
^{63}Ni	LSC → 98 % ± 4

→ Validation of radionuclide separation for ^{55}Fe and ^{63}Ni

Conclusion

- Optimized sequential method for the separation of Fe, Ni, Mo, Nb, and Zr from a single sample
- High and reproducible elution yields for all target elements over a wide concentration range
- Demonstrated robustness and reliability of the protocol under varying experimental conditions
- ^{55}Fe and ^{63}Ni results confirm the validity of the separation protocol

Perspectives

- Validation of the protocol for ^{94}Nb , ^{93}Mo , and ^{93}Zr (ongoing)
- Application of the protocol on activated steel sample

