Multi-array Electrode Module for Uranium Electrorefining Applying Automation Concept

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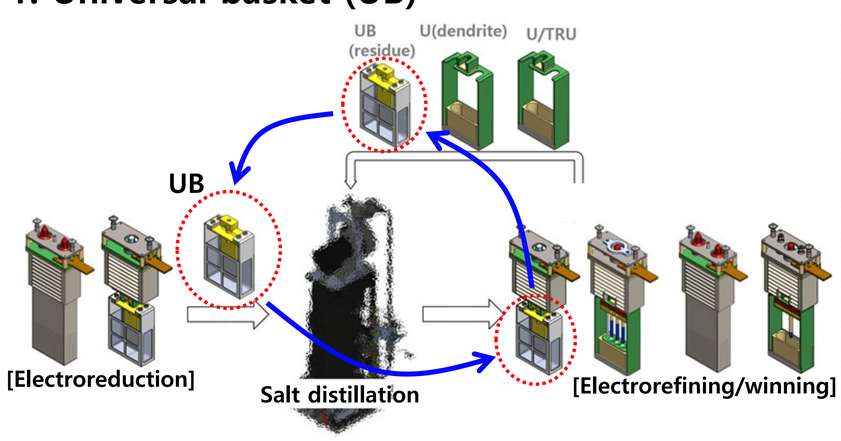
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Introduction

- **Pyroprocessing** is a technology that **separates and recovers uranium (U) and transuranic elements (TRUs)** from spent nuclear fuel using **molten salts** at high temperatures (500-650 °C). It offers advantages such as enhanced **proliferation resistance and the potential to recycle recovered materials** for use in fast reactors, ultimately **reducing the volume of high-level waste requiring disposal**.
- **Electrolysis recovery** is a crucial step in pyroprocessing, involving two main processes: **electrorefining** to selectively **recover U** from molten salts and **electrowinning** to **recover residual U and TRUs** using liquid cadmium electrodes.
- The **PRIDE** (Pyro Recovery process Integrated inactive DEmonstration facility) at the Korea Atomic Energy Research Institute previously used separate electrowinning and electrorefining units, leading to a **large system size and limitations in processing capacity** due to its single-batch operation.
- In this study, the performance testing of a **multi-array electrode module** for uranium recovery, incorporating automated concepts was detailed. The multi-array module type electrode (2 anodes, 3 cathodes) was implemented for comprehensive performance testing of the electrode modules.
- The performance test results, incorporating automated concepts for the uranium recovery electrode module, will be utilized to establish a basis for the design of a **large-scale pyroprocessing system**. These data will also be leveraged to address issues identified during experimentation and implement necessary improvements for optimized operational efficiency.

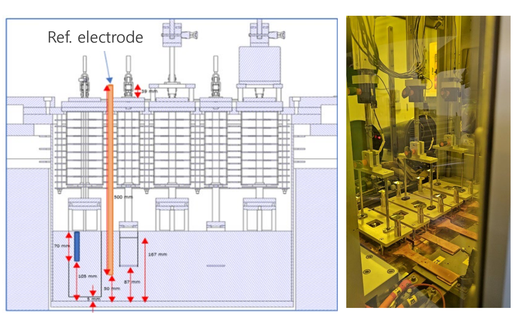
Strategies to Improve the Efficiency of the Electrolytic Recovery Process

1. Universal basket (UB)



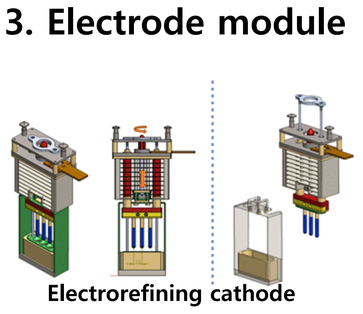
- ✓ Electrorefining and winning are carried out in **one electrolyzer**
- ✓ The electrorefining anode uses **the same UB** as the electroreduction cathode

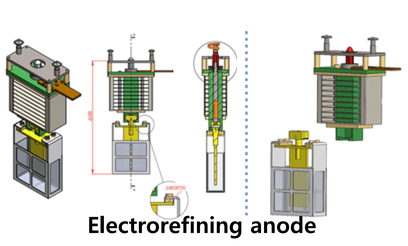
2. Multi-array

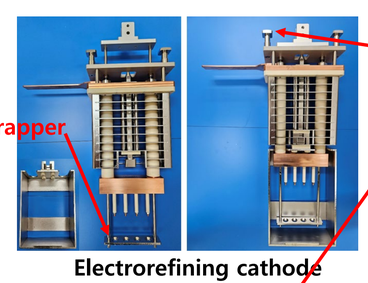


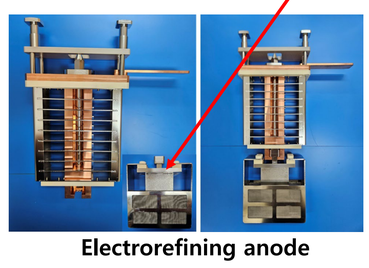
- ✓ **Reducing** overall apparatus **size**
- ✓ Allowing **continuos batch** process

3. Electrode module









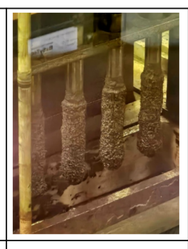
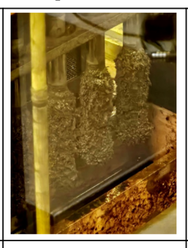
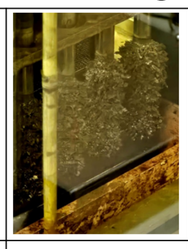
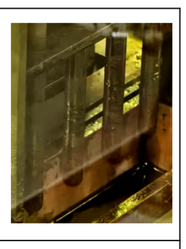
- ✓ The connection parts on top allow to be **transported by gantry**
- ✓ **Universal basket** used
- ✓ The upper and lower parts can be **separated**

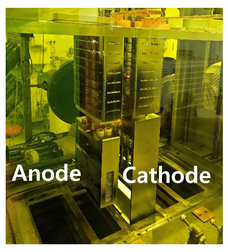
It allows the lower part to be loaded in the distillation process

Result

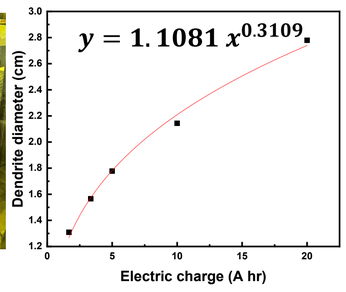
Preliminary Evaluation

- **Observation of U dendrite shape over time using 1 set (cathode-anode)**

						
Applied current	10 A	10 A	10 A	10 A	10 A	After scrapping
Applied time	10 min	20 min	30 min	60 min	120 min	
Electric charge	1.67 A hr	3.33 A hr	5 A hr	10 A hr	20 A hr	
Dendrite diameter	1.3 cm	1.6 cm	1.8 cm	2.1 cm	2.8 cm	
Theoretical deposition amount	4.943 g	9.857 g	14.8 g	29.6 g	59.2 g	



1 set electrode module





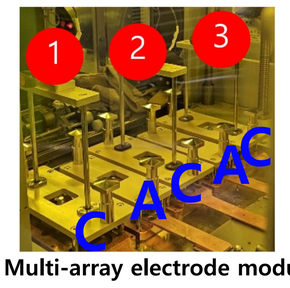
After applying 40 Ah

- ✓ **Prediction of U dendrite diameter** according to electric charge
- ✓ After applying **40 A hr**, **scrapping** was required considering the size of Al crucible

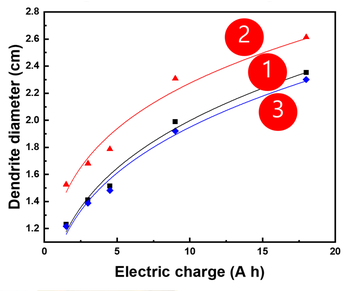
Process condition secured

Performance Test

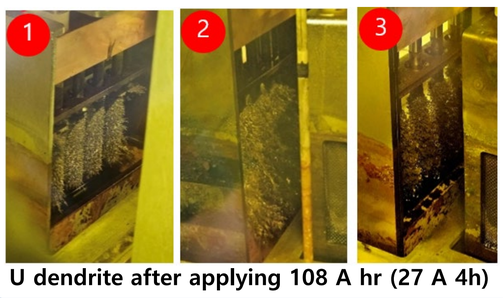
- **The multi-array electrode module (2 anodes, 3 cathodes) was implemented for comprehensive performance testing**



Multi-array electrode module



- ✓ Applying 27 A for 10, 20, 30, 60, 120 min
- ✓ It was confirmed that **more U dendrites** were deposited on **electrode 2** than on electrodes 1 and 3



U dendrite after applying 108 A hr (27 A 4h)

- ✓ Applying 27 A for 4 h
- ✓ **Excessive uranium dendrite** deposition was observed on the centrally **located cathode** compared to the other two

➡ Difficulty in securing **process conditions**

Performance Evaluation

- **Current efficiency calculation after salt distillation**



$$PRD_g = \frac{M_w}{n \times F} \times i \times t$$

PRD_g : Theoretical quantity of electrodeposition (g)
M_w : Molecular weight (g/mol)
n : # of electrons transferred
F : Faraday's constant (C/mol)
i : Current (A)
t : time (sec)

cathode	1	2	3
Charge	152.79 A hr	178.8 A hr	51.79 A hr
Theoretical quantity of electrodeposition	452.26 g	511.46 g	153.3 g
Actual deposited amount	402.78 g	499.51 g	101.54 g
Current efficiency of each cathode	89.0 %	97.6 %	66.2 %
Total Current efficiency		**89.9 %**	

- ✓ The current efficiency was calculated **at 89.9 %**
- ✓ But, **uneven electroplated** amount and **current distribution** by cathode appears to be a problem that needs to be addressed
- ✓ It is expected to be resolved by stirring the salt

Areas for Improvement

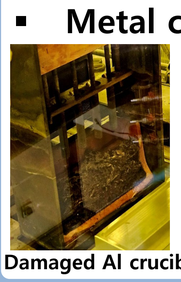
- **Salt stirring**



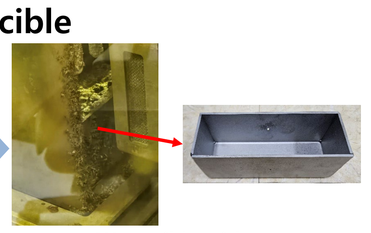
U dendrite after stirrer operation (27 A 3h)

- ✓ After operating the stirrer, electrodeposition was **more uniform** than before
- ✓ However, the amount of deposition remained higher on the central electrode
- ✓ The **stirring effect** was confirmed, and it is judged that an increase in the number of electrodes (C-A-C-A-C-A-C-A-C) will not pose a significant problem

- **Metal crucible**



Damaged Al crucible



W crucible with electrodeposited U dendrite

- ✓ **Al** crucible failure due to **thermal shock**
- ✓ Replaced with a **W** crucible, but encountered electrical conduction issues, resulting in U **electrodeposition on the crucible**
- ✓ Alternative measures, such as surface insulator coating, are needed

Conclusion

- Proposal of ways to strengthen inter-process connectivity and operational efficiency ➡ **Universal basket, Multi array, Automation**
- **Excessive U dendrite** deposition was observed on the **centrally located cathode**, leading to discrepancies in deposition amounts compared to other cathodes.
- Based on the U recovery quantity through salt distillation, the **current efficiency** was calculated at **89.9%**, demonstrating a high level of efficiency
- The **stirring effect** for uniform dendrite electrodeposition was confirmed, and **improvements to the crucible** for U recovery **are required**.