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(54) Title: STOICHIOMETRIC RECOVERY OF UF₄ FROM UF₆ DISSOLVED IN IONIC LIQUIDS

(57) Abstract: Described herein are methods for recovering uranium tetrafluoride (UF₄) from uranium hexafluoride (UF₆) by directly dissolving UF₆ in ionic liquids and recovering UF₄, which can be processed to obtain UO₂ (s) or uranium metal.



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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC - C01G 43/00; G21C 19/48; G21C 21/00 (2021.01)

CPC - C01G 43/025; G21C 19/48; G21C 21/00; G21C 3/623

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2011-107156 A (Japan Atomic Energy Agency) 2 June 2011 (02.06.2011) Abstract; para [0017]	1-17
A	JP 2016-008891 A (Hitachi Ltd) 18 January 2016 (18.01.2016) Abstract; para [0024], para [0014]	1-17
A	WO 2015/059777 A1 (Hitachi Ltd) 30 April 2015 (30.04.2015) Abstract; pg 4 ln 140; pg 3 ln 118	1-17
A	US 2014/0374272 A1 (Savannah River Nuclear Solutions) 25 December 2014 (25.12.2014) Abstract; para [0038]	1-17
A	US 2004/0170550 A1 (Kawamra et al.) 2 September 2004 (02.09.2004) Abstract; Figures 2 and 3	1-17

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 August 2021 (23.08.2021)

Date of mailing of the international search report

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Name and mailing address of the ISA/US

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INTERNATIONAL SEARCH REPORT

International application No.

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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

-----see supplemental box-----

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-17

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

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-----continued from Box III-----

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-17 is directed towards a method for converting uranium hexafluoride (UF₆) to uranium tetrafluoride (UF₄), comprising dissolving UF₆ directly into a room temperature ionic liquid at concentrations of 0.01 M to 3.0 M; incubating the solution for a period of time; and adding water to the solution to precipitate solid UF₄.

Group II: Claim 18-31 is directed towards a method for producing UF₆ (2-) comprising dissolving UF₆ directly into a room temperature ionic liquid at concentrations of 0.01 M to 2.5 M and incubating the solution for a period of time.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features:

Group I requires a method for converting UF₆ to UF₄, and adding water to the solution to precipitate solid UF₄; not required by groups II

Group II requires a method for producing UF₆ (2-), not required by groups I

Shared Technical Features:

Groups I-II share the common feature of dissolving UF₆ directly into a room temperature ionic liquid at concentrations of 0.01 M to 2.5 M and incubating the solution for a period of time. However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is obvious over US 2014/0374272 A1 to Savannah River Nuclear Solutions LLC (hereinafter Savannah). Savannah discloses a of dissolving UF₆ directly into a room temperature ionic liquid (para [0038], uranium hexafluoride can be hydrolyzed by solution in water) incubating the solution for a period of time (para [0038], the mixture thus formed can be heated to a temperature afrom 100-300 celsius for a time greater than 12 hours to form nanoparticles). Although Savannah does not specifically state that this dissolution is at concentrations of 0.01 M to 2.5 M; it would have been obvious that the method disclosed by Savannah can lead to such concentration depending on the length of the process; through routine experimentation.

As the shared technical features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups. Therefore, Groups I-II lack unity under PCT Rule 13.