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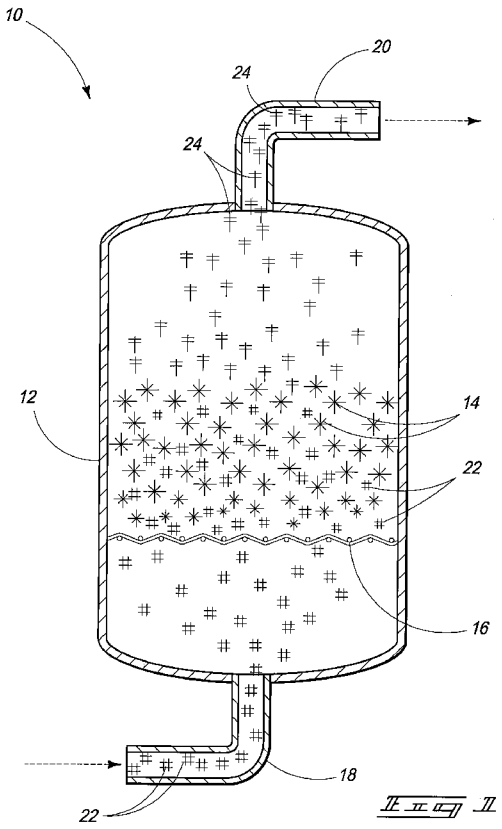
(54) **Title**: SYSTEMS AND METHODS FOR TREATING MATERIAL



(57) **Abstract**: Systems for treating material are provided that can include a vessel defining a volume, at least one conduit coupled to the vessel and in fluid communication with the vessel, material within the vessel, and NF_3 material within the conduit. Methods for fluorinating material are provided that can include exposing the material to NF_3 to fluorinate at least a portion of the material. Methods for separating components of material are also provided that can include exposing the material to N F3 to at least partially fluorinate a portion of the material, and separating at least one fluorinated component of the fluorinated portion from the material. The materials exposed to the NF_3 material can include but are not limited to one or more of U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb.

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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Systems and Methods for Treating Material

CLAIM FOR PRIORITY

This application claims priority to U.S. Provisional Patent Application Serial No. 61/084,352 entitled "Application of Nitrogen Trifluoride in the Nuclear Fuel Cycle", which was filed on filed July 29, 2008, the entirety of which is incorporated by reference herein.

TECHNICAL FIELD

The present disclosure relates to systems and methods for treating material. Particular embodiments of the disclosure describe systems and/or methods for treating uranium material, actinide material, and/or fission product materials.

BACKGROUND

For a variety of reasons, it can be desirable to treat either mined or created materials. This treatment can include alteration to create another form of the material or components of the material that allows for specific processing and/or alternative separation techniques to be utilized, for example. Components of materials that can make alternative treatment, specific processing, and/or separation techniques desirable include but are not limited to toxic, regulated, and/or valuable materials such as uranium materials, actinide materials, and/or fission materials.

As an example, uranium materials can be treated to provide a uranium fluoride material which can be used in the uranium fuel cycle. Uranium fluorination is performed in the existing nuclear fuel cycle to fluorinate uranium recovered both from ore and/or from spent nuclear fuel. These fluorination processes rely on many hazardous, highly reactive, and highly toxic fluorinating agents. As an example of a currently used process, in a reprocessing plant, uranium is recovered as uranyl nitrate hexahydrate (UNH), calcined to uranium trioxide (UO_3), reduced to uranium dioxide (UO_2) using hydrogen derived from

cracked ammonia, converted to UF_4 by HF (NFPA rating Health =3; Reactivity = 2) at 300 to 500°C, and finally converted to UF_6 by F_2 (NFPA rating Health = 4; Reactivity = 4) at 500°C. The process for converting natural uranium to UF_6 is similar.

Fluorinating agents used or proposed for use in the fluoride volatility-based reprocessing approach include hydrogen fluoride (HF) and/or diatomic fluorine (F_2), difluorodioxide (FOOF), chlorine trifluoride (ClF_3), and bromine trifluoride (BrF_3). These fluorinating agents are considered highly toxic, highly reactive, and hazardous and some can produce hazardous by-products. In particular, ClF_3 fluorination by-products are explosive or can react explosively with water or organics. These highly toxic reagents necessitate the use of substantial safety and environmental controls. These controls can add substantial cost to the processing of uranium materials.

SUMMARY OF THE DISCLOSURE

Systems for treating material are provided that can include a vessel defining a volume, at least one conduit coupled to the vessel and in fluid communication with the vessel, NF_3 material within the conduit, and material within the vessel, the material including one or more actinides and/or fission products such as but not limited to U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb.

Methods for fluorinating material are provided that can include exposing the material to NF_3 material to fluorinate at least a portion of the material. The material exposed to the NF_3 material can include one or more actinides and/or fission products such as but not limited to U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb.

Methods for separating components of material are also provided that can include exposing the material to NF_3 material to at least partially fluorinate a portion of the material, and separating at least one fluorinated component of the fluorinated portion from the material. The material exposed to the NF_3 material can include one or

more actinides and/or fission products such as but not limited to U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the disclosure are described below with reference to the following accompanying drawings.

Fig. 1 is a system according to an embodiment of the disclosure.

Fig. 2 is a depiction of data that may be acquired utilizing an embodiment of the systems and/or methods of the present disclosure.

Fig. 3 is a depiction of data that may be acquired utilizing an embodiment of the systems and/or methods of the present disclosure.

DESCRIPTION

Systems and methods for treating uranium material are provided with reference to Figs. 1-3.

Referring to Fig. 1, a system 10 is shown that includes a vessel 12 defining a volume, and housing material 14(*). Vessel 12 can be constructed of inorganically inert materials capable of withstanding extreme temperatures and configured to heat the volume and material 14. This disclosure should not be limited to how vessel 12 is depicted. Vessel 12 is an example of one of many vessels that may be utilized according to the methods and systems of the present disclosure. Material 14 can be supported by support 16. Support 16 can be constructed of an inert mesh material and provide support for material 14 as well as passageways for reactants.

Material 14 can include material previously fluorinated utilizing the harsh fluorinating techniques utilized in the past. Material 14 can include one or more actinides and/or fission products such as but not limited to U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb. Material 14 can be a material that is utilized in the nuclear

fuel cycle, so-called nuclear materials. Material 14 can be a uranium material, a plutonium material, and/or a thorium based material.

Material 14 can be a uranium material. The uranium material can include one or more of uranium ore, uranium oxide, processed or even partially processed uranium, slag uranium, nuclear fuel, irradiated nuclear fuel, uranium yellow cake, and/or spent nuclear fuel. Material 14 can be considered a uranium material, regardless of the amount of uranium material. For example, coal ash containing 0.25% to about 0.5% (wt./wt.) uranium can be considered a uranium material. The uranium material can include actinides. The uranium material can include Pu, Np, Mo, Ru, and Tc, for example.

Material 14 can also be substantially free of uranium and include actinides and/or fission products. Material 14 can include one or more of Pu, Np, Mo, Ru, and Tc, as well as one or more of the non-fluorinated and/or fluorinated elements listed in Tables 1 and/or 2 below.

Material 14 can be a pure, heterogeneous, or homogenous blend of solid material. The material can be pelletized to a predefined uniform size, for example. Material 14 may be acquired from multiple sources and some of these sources can dictate the application of the systems and methods of the present disclosure. Material 14 may have been treated to remove other materials. For example, material 14 may have been fluorinated to remove uranium and/or specific fission products.

For example, and in accordance with implementations of embodiments of the disclosure, the systems and methods of the present disclosure can also be utilized in any other industry wherein fluorination may be desired as a part of a processing strategy; this includes but is not limited to applications such as mining (the treatment of slag containing elements and/or equivalent elements to the elements described herein), environmental remediation (the

treatment of RCRA waste containing elements and/or equivalent elements to the elements described herein), waste treatment, and/or other applications.

Conduits 18 and 20 can be coupled with vessel 12. These conduits can be configured to convey gaseous materials such as reactants and/or products. The conduits may be configured with valves to control flow within same and/or may be constructed of inert materials such as those used to construct vessel 12. In accordance with an example embodiment, conduit 18 may be configured to convey material 22 (#).

Material 22 can include NF_3 as well as other components, such as Ar and/or N_2, for example. Part or all of material 22 can be in the gaseous phase and may be heated prior to entering the conduit to accomplish same. The present disclosure provides that NF_3 is an effective fluorinating agent for converting uranium compounds to the volatile uranium fluoride compounds such as UF_6 which is the feed stock into the uranium enrichment processes.

NF_3 can be considered mildly toxic in comparison to the toxic and extremely toxic fluorinating reagents described in the background. Utilizing NF_3 can substantially eliminate most, if not all, of the hazards associated with the existing fluorinating agents. NF_3 can be considered non-reactive at room temperature, having the toxicity equivalent to moth balls, while exhibiting similar thermal fluorinating power to that of F_2 or HF, in these applications. NF_3 has low toxicity and a non-reactive character (NFPA Rating Health = 1; Reactivity = 0), and can be used to replace the highly toxic and highly reactive HF and F_2 as the fluorination agent of choice in many stages of the nuclear fuel cycle.

By directly substituting NF_3 material, 1) the safety of nuclear processing operations can be dramatically improved over existing fluorinating agents and 2) different thermal reaction sensitivities and

volatilities can be leveraged to provide an improved fluoride volatility reprocessing flow sheet. The minimal toxicity of NF_3 gives it a distinct advantage over highly toxic HF and F_2. The lesser reactivity of NF_3 compared to HF and F_2 offers the potential to improve the selectivity of the thermal fluorination reaction and selectively convert spent fuel constituents to volatile fluorides thus enhancing purification factors for the valuable fuel and other constituents. These features might be leveraged to provide proliferation resistance.

In accordance with example implementations, material 22 can be exposed to material 14 within vessel 12 to form a fluorinated material 24 (‡). Fluorinated material 24 can have substantially different physical properties of portions or all of material 14. In accordance with example implementations, the systems and methods of the present disclosure can be utilized to take advantage of the differences in these physical properties. For example, material 14 may have melting, sublimation, and/or boiling points substantially different than melting, sublimation, and/or boiling points of portions or all of fluorinated material 24. As such, material 14 may be exposed to material 22 at a temperature and/or pressure that provides for the fluorination and/or removal of specific elements of material 14. For example, a majority of elements of material 14 may be fluorinated at one temperature, but only specific fluorinated elements may be volatile and/or removed from material 14 at this same temperature. By dynamically configuring system 10 through temperature and/or pressure ramps, portions of material 14 can be extracted and/or purified. The systems and methods of the present disclosure can include dynamically controlling the temperature of the contents of vessel 12 to selectively fluorinate portions of material 14 and mobilize the fluorinated material 24, such as volatilizing the fluorinated material 24. This can separate a fluorinated portion of the uranium material from the uranium material.

In accordance with a particular embodiment, material 14 can include uranium oxide (such as UO_2 and/or UO_3) and this uranium oxide can be exposed to NF_3 material 22 to form fluorinated material 24 that can include U and F, such as UF_6, for example. UF_6 has substantially different physical properties than uranium oxide. In the case where the volume of vessel 12 is maintained above the sublimation point or above the boiling point of UF_6 but below the melting point of uranium oxide, the UF_6 generated can be conveyed into conduit 20 and thus separated from the remaining material 14.

The temperature of the contents of vessel 12 may be manipulated to facilitate the dynamic fluorination and separation of materials. The temperature of the contents may be controlled to provide a minimum temperature of 50°C which can be sufficient to facilitate the fluorination of U metal. As an example, a temperature within the volume of vessel 12 may be greater than 400°C. Material 24 need not necessarily be in the gaseous phase to be removed from vessel 12; material 24 can be composed of liquid and gases and conveyed to conduit 20 through flow regulation of the material 22 received from conduit 18. In accordance with example implementations, the mildly toxic NF_3 can be used as a fluorinating agent for uranium and other actinides and fission products to form volatile or non-volatile fluorides of same.

This is just one example of a system and method that can be used to significantly reduce the number of and simplify the process steps required to recover the valuable fuel and chemical (e.g. noble and precious metals) constituents in spent nuclear fuel. Through reducing and/or simplifying the process steps, the systems and methods of the present disclosure can leave a substantially smaller environmental footprint than the PUREX reprocessing flow of the prior art.

Example industrial applications of the systems and methods of the current disclosure include, but are not limited to: 1) conversion of

uranium yellow cake (or precursors) recovered from uranium ores to the volatile UF_6; 2) converting uranium dioxide (UO_2) recovered from nuclear fuel reprocessing to UF_6; 3) reprocessing of uranium recovered from spent nuclear fuel reprocessing or recycle plants; 4) pretreating to affect the release of volatile fission products such as iodine, tritium, and/or krypton from spent nuclear fuel; and/or 5) converting U, UO_2, Pu, PuO_2, and potentially other actinide oxides and metals to volatile fluorides to separate them from fission products (replacement fluorinating gas in the fluoride volatility nuclear fuel recycle process).

The systems and methods of the present disclosure can be utilized throughout the nuclear fuel cycle. NF_3 can be used to effectively fluorinate and convert various uranium oxidation states and compounds to the volatile uranium hexafluoride, which is the uranium process gas used in uranium isotope enrichment plants. NF_3 can be used to fluorinate other actinides and fission products to volatile or non-volatile compounds.

Thermogravimetric (TG) and differential thermal analysis (DTA) methods can be used to determine the thermal sensitivity and effectiveness of NF_3 as a fluorinating agent for converting uranium metal and various uranium oxides, oxyfluorides, and fluorides to the volatile UF_6, for example. To accommodate the reactivity of NF_3, the thermoanalytical instrument can be modified to have only nickel surfaces exposed to the high temperature gas. TG can measure mass change and DTA can measure temperature differences between the sample and a reference material at isothermal conditions or as the sample is heated or cooled at controlled rates under a controlled non-reactive or reactive gas atmosphere.

Both methods provide thermal reaction sensitivities and reaction kinetics. Mass changes can provide insights on the reaction path. The heat changes observed by the DTA can provide whether a reaction is endothermic (requires heat) or exothermic (produces heat).

Exothermicity can indicate that the reaction will proceed easily while endothermicity can indicate that heat must be provided to make a reaction occur.

As illustrated in Fig. 2 for UO_2 and Fig. 3 for UO_3, NF_3 material can convert uranium oxides to UF_6 at temperatures near 400°C when heated at 0.083 K/s in flowing 5% NF_3/Ar. Similar positive results can be obtained for triuranium octaoxide (U_3O_8).

Fig. 2 illustrates that after some preliminary exothermic reactions (heat flow plot), NF_3 substantially converts the UO_2 to UF_6 (mass plot). Fig. 3 shows that after an initial exothermic (heat flow plot) reaction, NF_3 substantially converts UO_3 to UF_6 (mass plot) in an exothermic reaction. Comparison of Fig. 2 with Fig. 3 illustrates the differences in thermal sensitivities that might be leveraged to recover valuable fuel constituents and differences in reaction pathways as these uranium oxides are converted to UF_6. Similar positive results can be obtained for uranium metal, triuranium octaoxide, uranium tetrafluoride, uranyl fluoride, ruthenium dioxide, molybdenum oxides, and/or for technetium compounds.

NF_3 is an effective fluorinating/oxidizing agent for both uranium and technetium (Tc) compounds. NF_3 can effectively convert uranyl fluoride (UO_2F_2) and uranium tetrafluoride (UF_4) to volatile UF_6, and technetium dioxide (TcO_2) and/or pertechnetate to volatile technetium hexafluoride (TcF_6). Thermoanalytical data demonstrates that thermal NF_3 can successfully convert uranium metal and the common uranium oxides uranium dioxide (UO_2), triuranium octaoxide (U_3O_8), and uranium trioxide (UO_3) to UF_6.

The ability of certain actinides to form volatile fluorides has played a significant role in the nuclear fuel cycle and has the potential to play a more significant role as the basis for a compact reprocessing approach. The systems and methods of the present disclosure may be utilized during fluoride volatility reprocessing flow sheet or as a

pretreatment to cause release of volatile radioactive fission products iodine-129, tritium, and krypton, or to convert recovered uranium to uranium hexafluoride for isotopic re-enrichment.

Table 1 below provides the thermogravimetric analyzer (TGA)-measured onset temperatures for the nitrogen trifluoride (NF_3)-fluorination (10% NF_3 in argon) of several uranium compounds and fission products that form volatile fluorides. These can be determined at varied rates such as isothermal, 2, 5 or 10°C/min; heating rate can affect the measured onset temperature and in general significant reaction rates will occur at temperatures up to 100°C less than the TGA-measured onset temperature. In addition to the TGA heating rate, the measured fluorination temperatures depend on a number of factors including particle size and fluorination gas concentration. In accordance with example implementations, NF_3 can be an effective fluorination agent from temperatures ranging from room temperature to over 600°C.

Table 1. Thermogravimetric Analyzer (TGA)-Measured Onset Temperatures for Fluorination Reactions with 10% Nitrogen Trifluoride (NF_3)/Argon.

Material	Initial Fluorination, °C	Volatile Fluoride Formation, °C
Elemental Uranium (U)	40 – 120	250
Uranium Dioxide (UO_2)	400	540
Uranium Trioxide (UO_3)	230	370
Triuranium Octaoxide (U_3O_8)	370	430
Uranium Tetrafluoride (UF_4)	350	350
Ruthenium Dioxide (RuO_2)	400	480
Dirhodium Trioxide (Rh_2O_3)	250	Not observed
Elemental Molybdenum (Mo)	316	316
Molybdenum Dioxide (MoO_2)	305	305
Molybdenum Trioxide (MoO_3)	410	410
Technetium Dioxide (TcO_2)	40	40

According to an example implementation for removing select portions and/or elements of material 14, a method for separating components of material 14 can include exposing material 14 to NF_3 material to at least partially fluorinate a portion of material 14. The method can then include separating at least one fluorinated component of the fluorinated portion from the uranium material. In accordance with example implementations, the fluorinated portion of material 14, perhaps part or all of material 24, can include U and F. The at least one fluorinated component of the fluorinated portion can also include U and F. In this manner, material 14 including uranium oxide can be fluorinated and the uranium fluoride removed from the remainder of material 14.

Uranium hexafluoride (UF_6) volatility can be exploited during uranium isotope enrichment gaseous diffusion or gas centrifuge processes used to produce ^{235}U-enriched uranium for nuclear reactor fuel and ^{235}U-weapons. In addition to use in uranium enrichment, actinide volatility could provide the basis for advanced nuclear fuel reprocessing relying on differences in thermal reaction sensitivities and volatilities of residual fuel components, fission products, and actinides arising from irradiation. Actinide volatility reprocessing can provide a simple and compact process for recovering U and Pu from spent nuclear fuel.

The differences in the boiling point or sublimation points for the residual fuel-, fission products-, and actinide fluorides can be exploited through an actinide volatility-based processing approach. The systems and methods of the present disclosure can utilize the reaction thermal sensitivity as well as fractional distillation to separate and recover the valuable used fuel constituents and if desired other valuable constituents such as noble metals.

The actinide volatility-based processing approach can be enhanced through the use of a less aggressive fluorinating agent to increase separation factors and simplify the fractional distillation approach needed to separate and recover volatilized materials. The actinide volatility processing approach can be used to fluorinate the residual fuel (U or Pu), key actinides created during irradiation, and fission products. Embodiments of the systems and methods of the present disclosure can be utilized to perform this approach through providing NF_3 material as an effective fluorinating/oxidizing agent that will react with different compounds at different reaction temperatures and rates.

In accordance with these embodiments, NF_3 material can have several potential applications in the nuclear fuel cycle. For example: it can be used to prepare the UF_6 feed for uranium isotope enrichment; it can be used as the fluorinating agent in the actinide

fluoride volatility-based reprocessing scheme; and it can be used as a head-end treatment to separate the bulk of the uranium from the fission products and actinides in used fuel.

Because of potential differences between the thermal fluorination chemistry of NF_3 and HF/F_2, NF_3 can provide a more tunable chemistry and thus provide greater separation factors during recovery of uranium, plutonium, and neptunium from spent nuclear fuel. This chemistry may also be used to cause release of volatile radionuclides in a form that can easily be managed.

As another example, the method for separating components of material 14 can include exposing material 14 to NF_3 material to at least partially fluorinate a portion of material 14. The method can then include separating at least one fluorinated component of the fluorinated portion from the uranium material. In accordance with example implementations, the fluorinated portion of material 14, perhaps part or all of material 24, can include F and U, Pu, Np, Mo, Ru, and/or Tc. The at least one fluorinated component of the fluorinated portion can include F and U, Pu, Np, Mo, Ru, and/or Tc. In this manner, material 14 including irradiated nuclear fuel can be fluorinated and the uranium fluoride as well as actinides removed from the remainder of material 14.

Material 24 can also be treated upon removal from vessel 12, for example, by separation techniques such as high pressure distillation. In accordance with another example implementation, the fluorinated component separated from the uranium material can include F and at least two of U, Pu, Np, Mo, Ru, and/or Tc. The method can further provide for distilling the fluorinated component to acquire a compound that includes F and one of the U, Pu, Np, Mo, Ru, and/or Tc. In this manner highly valuable and/or toxic elements can be removed from the material 24.

Table 2 provides the melting and boiling or sublimation temperatures for fluorides that may form during the fluorination process. The table is divided into three sections based on the relative volatility of the substance or fluoride. Through temperature control, the volatiles can be separated from the non-volatiles and the volatiles can be separated from each other through dynamic reaction and/or selective distillation.

Table 2: Melting and Boiling or Sublimation Temperatures of the Fluorides of Residual Fuel, Fission Products, and Actinides.

Highly Volatile			Moderately Volatile			Nonvolatile		
Substance	T_{melt}, °C	T_{boil}, °C	Fluoride	T_{melt} °C	T_{boil} or T_{subl} °C	Fluoride	T_{melt}, °C	T_{boil} or T_{subl}, °C
Kr	-157.2	-153.4	IF_7	5	4	AgF	435	decomposes
CF_4	-184	-129	MoF_6	17.6	33.9	AgF_2	690	decomposes
Xe	-111.8	-108.1	RuF6	32.1	45.9	AmF_4		513
TeF_6		-38.6	NpF_6	54.8	55.2	RhF_3		600
SeF_6		-34.5	TcF_6	37.9	55.2	SnF_4		705
			UF_6	64	56.5	ZrF_4	912	918
			PuF_6	51.9	62.2	PuF_4	1037	927
			IF_5	9.4	98	CsF	703	1231
			SbF_5	6	142.7	RbF	760	1410
			NbF_5	80	235	UF_4	1036	1450
			RuF_5	101	70	AmF_3	1427	2067

Highly Volatile			Moderately Volatile			Nonvolatile		
			RhF_5		95.5	CmF_3	1406	
			RhF_6	70	73.5	YF_3	1136	2230
						BaF_2	1353	2260
						EuF3	1276	2280
						GdF_3	1380	2280
						$\cdot CeF_4$	838	decomposes
						CeF_3	1430	2330
						PmF_3	1410	2330
						SmF_3	1306	2330
						SrF_2	1400	2460

Through converting uranium compounds to UF_6, and technetium compounds to volatile technetium fluorides, the systems and methods of the present disclosure may be used as a direct substitute for aqueous reprocessing or as a head-end treatment in an aqueous-based reprocessing flow sheet.

In accordance with example implementations, utilizing the systems and methods of the present disclosure, as well as the data of tables 1 and 2, very focused fluorination and separation can be performed to recover and/or separate valuable and/or toxic materials. For example, highly valuable uranium can be recovered from ore or

spent fuel. As another example, Mo, particularly Mo^{99}, can be recovered from irradiated fuel and/or recovered from an irradiated target for use as a medical isotope. Still further, toxic compounds whose presence dictates that the material they are present in be stored at great expense, can be removed from the material and thereby lessen the cost of material storage.

CLAIMS

What is claimed is:

1. A system for treating uranium material, the system comprising:
a vessel defining a volume;
at least one conduit coupled to the vessel and in fluid communication with the vessel;
uranium material within the vessel; and
NF_3 material within the conduit.

2. The system of claim 1 wherein the NF_3 material is in the gaseous state.

3. The system of claim 1 wherein a temperature within the volume of the vessel is greater than 400°C.

4. The system of claim 1 wherein the NF_3 material includes Ar.

5. The system of claim 1 wherein the uranium material includes uranium oxide.

6. The system of claim 1 wherein the uranium material include actinides.

7. A method for fluorinating uranium material, the method comprising exposing the uranium material to NF_3 material to fluorinate at least a portion of the uranium material.

8. The method of claim 7 wherein the uranium material comprises uranium oxide and the fluorinated portion comprises uranium fluoride.

9. The method of claim 8 wherein the uranium oxide is one or both of UO_2 or UO_3 and the fluorinated portion comprises UF_6.

10. The method of claim 7 wherein uranium material comprises one or more of Pu, Np, Mo, Ru, and Tc; and the fluorinated portion comprises one or more PuF_6, NpF_6, MoF_6, RuF_6 and TcF_6.

11. The method of claim 7 wherein the uranium material comprises one or more of irradiated nuclear fuel, uranium ore, uranium slag, and partially fluorinated uranium material.

12. The method of claim 7 wherein a temperature of the uranium material is greater than 400°C during the exposing.

13. The method of claim 7 wherein the uranium material is exposed to the NF_3 material within a vessel.

14. The method of claim 13 further comprising separating the fluorinated portion from the uranium material within the vessel.

15. The method of claim 14 wherein the separating comprises dynamically controlling the temperature of the contents of the vessel to selectively fluorinate portions of the uranium material and volatilize the fluorinated portions.

16. A method for separating components of uranium material, the method comprising:
exposing the uranium material to NF_3 material to at least partially fluorinate a portion of the uranium material; and
separating at least one fluorinated component of the fluorinated portion from the uranium material.

17. The method of claim16 wherein the fluorinated portion comprises U and F.

18. The method of claim 17 wherein the fluorinated component separated from the uranium material comprises U and F.

19. The method of claim 16 wherein the fluorinated portion comprises F and one or more of U, Pu, Np, Mo, Ru, and Tc.

20. The method of claim 19 wherein the fluorinated component separated from the uranium material comprises F and one or more of U, Pu, Np, Mo, Ru, and Tc.

21. The method of claim 19 wherein the fluorinated component separated from the uranium material comprises F and at least two of U, Pu, Np, Mo, Ru, and Tc.

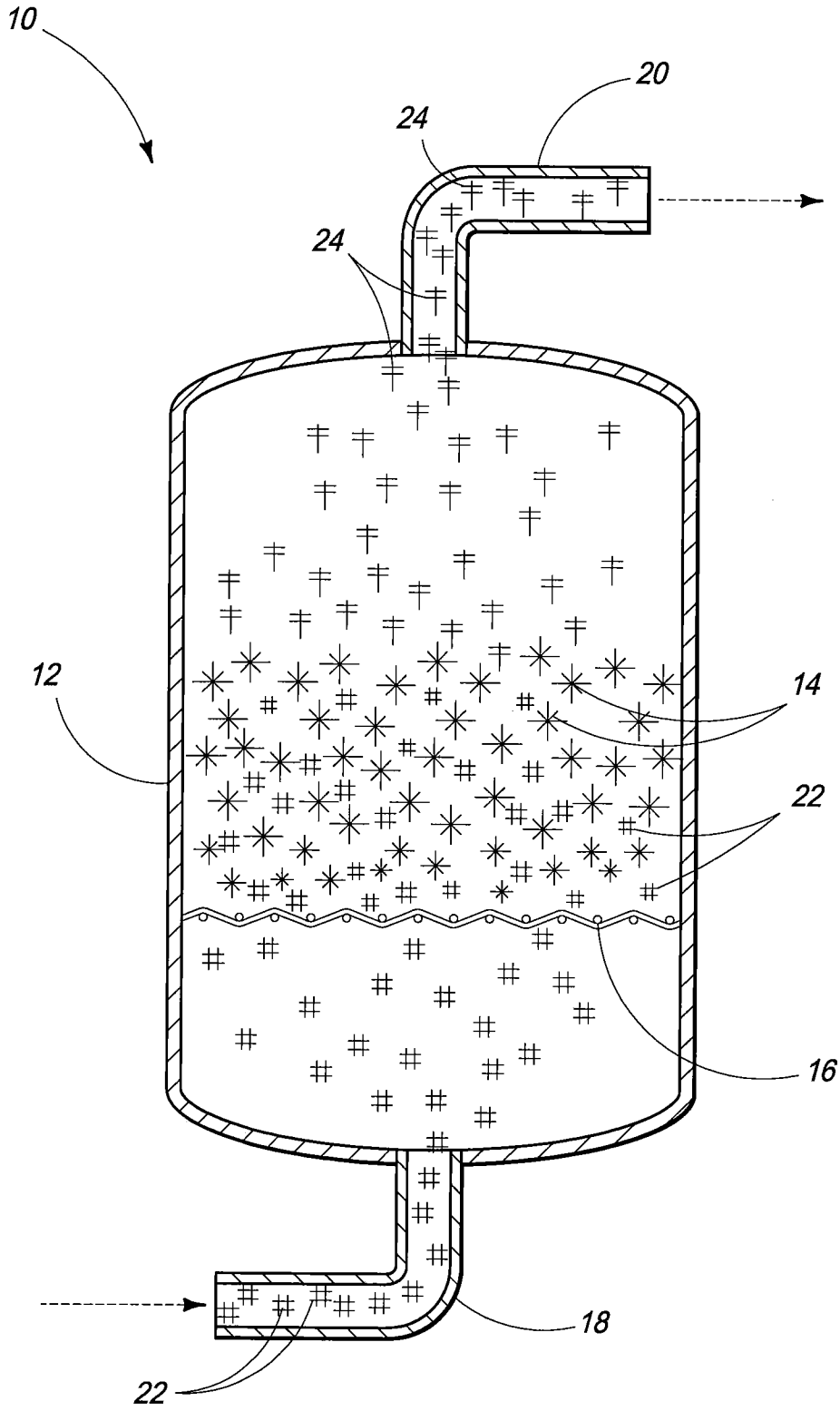
22. The method of claim 21 further comprising distilling the fluorinated component to acquire a compound comprising F and one of U, Pu, Np, Mo, Ru, and Tc.

23. A method for fluorinating material, the method comprising exposing the material to NF_3 material to fluorinate at least a portion of the material, the material exposed to the NF_3 material comprising one or more of U, Ru, Rh, Mo, Tc, Np, Pu, Sb, Ag, Am, Sn, Zr, Cs, Th, and/or Rb.

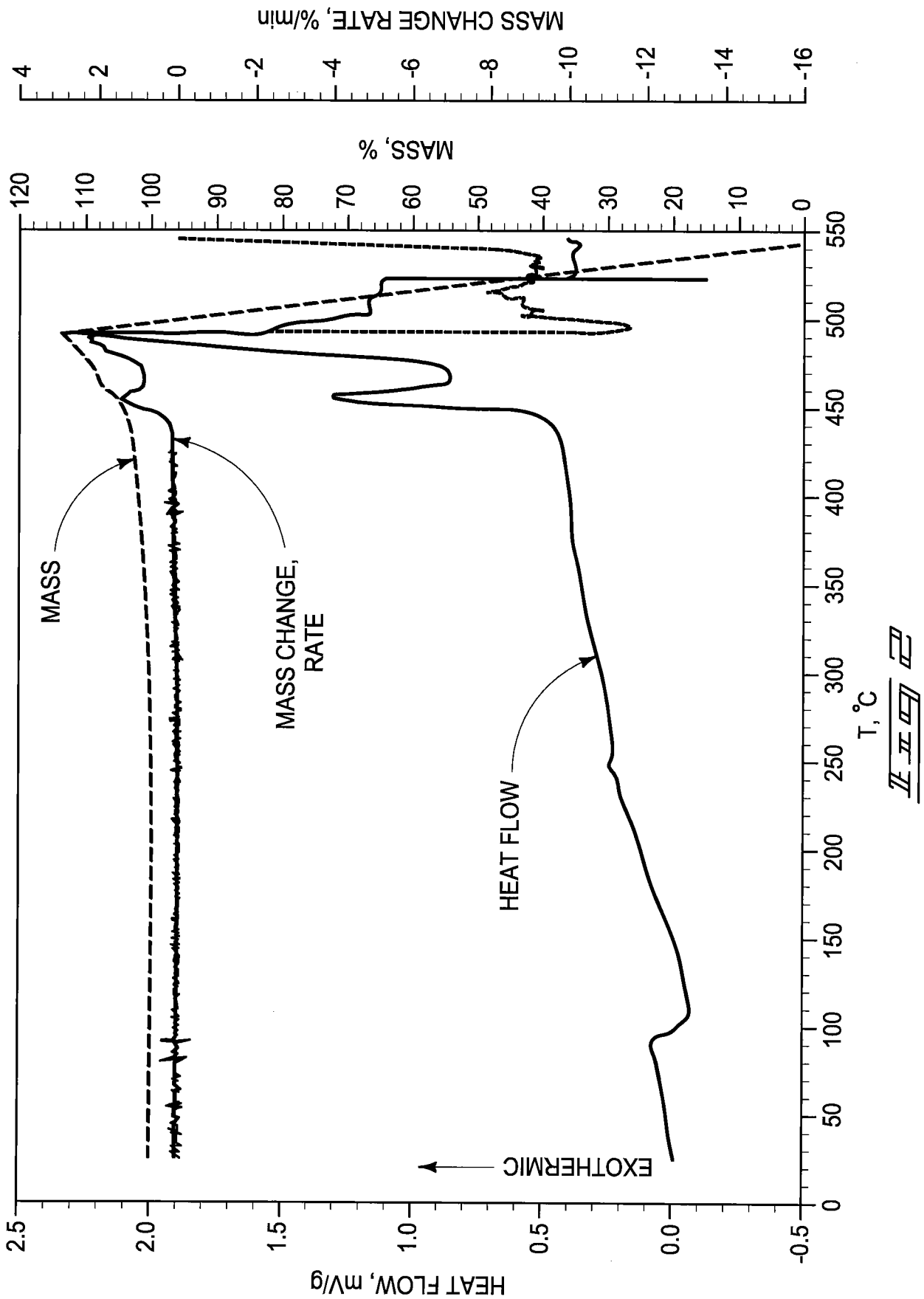
24. The method of claim 23 wherein the material comprises one or more of U, Pu, Np, Mo, Ru, and Tc.

25. The method of claim 23 the material exposed to the NF_3 material is at least partially fluorinated, the method further comprising
separating at least one fluorinated component of the fluorinated portion from the uranium material.

26. The method of claim 23 wherein material comprises one or more of Pu, Np, Mo, Ru, and Tc; and the fluorinated portion comprises one or more PuF_6, NpF_6, MoF_6, RuF_6 and TcF_6.



Фиг. 1


MASS CHANGE RATE, %/min
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
MASS, %
120
110
100
90
80
70
60
50
40
30
20
10
0
550
500
450
400
350
300
250
200
150
100
50
0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
HEAT FLOW, mV/g
T, °C
EXOTHERMIC
MASS
MASS CHANGE, RATE
HEAT FLOW

Фиг. 2

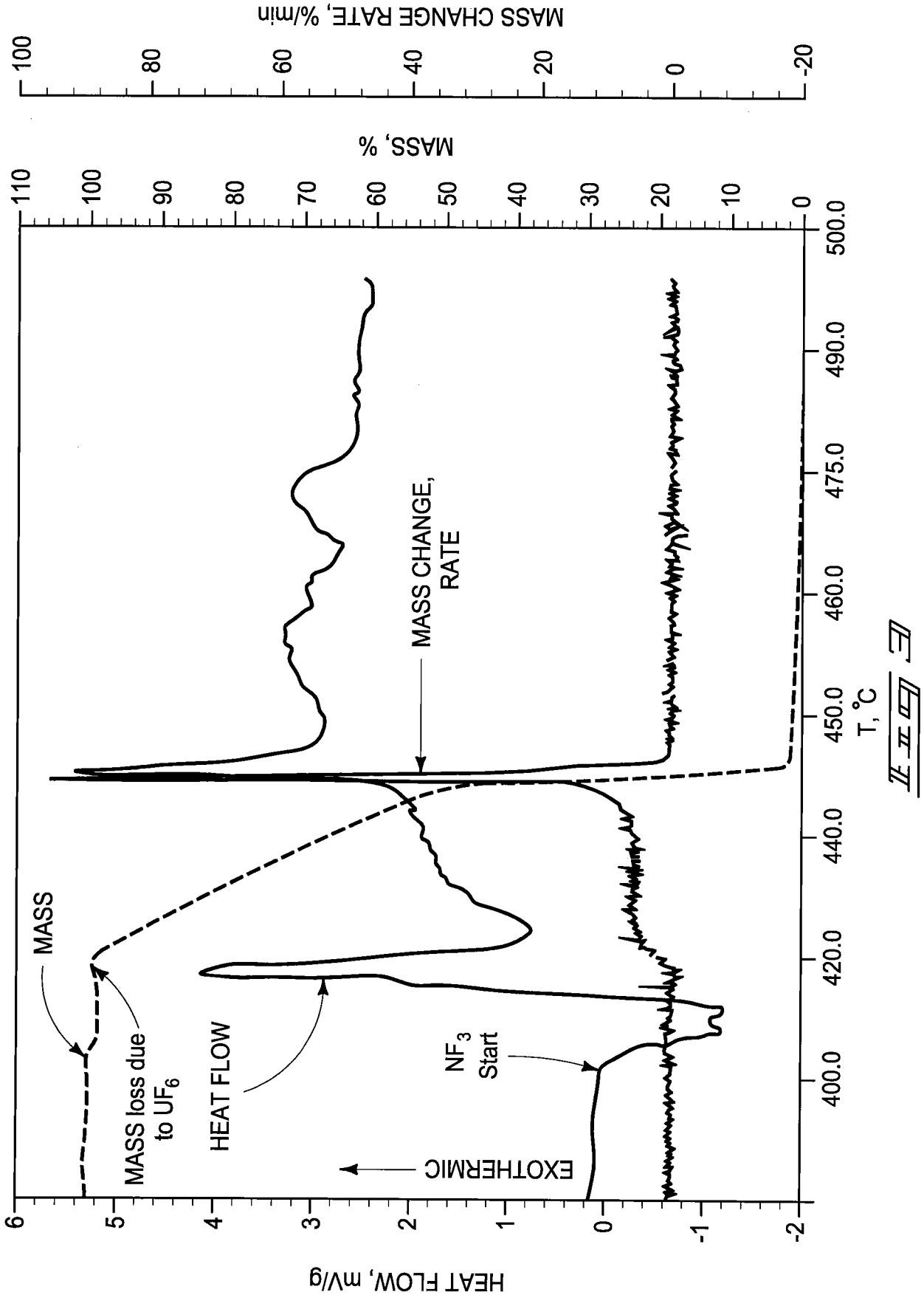

MASS CHANGE RATE, %/min
100
80
60
40
20
0
-20
MASS, %
110
100
90
80
70
60
50
40
30
20
10
0
MASS
MASS loss due to UF_6
HEAT FLOW
NF_3 Start
EXOTHERMIC
MASS CHANGE, RATE
6
5
4
3
2
1
0
-1
-2
HEAT FLOW, mV/g
400.0
420.0
440.0
450.0
460.0
475.0
490.0
500.0
T, °C

Fig. 3