Taggant for Nuclear Material in the Enrichment Process

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4 May 2012
Outline

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Supports efforts to reduce nuclear terrorism & maintain control of nuclear resources

Purpose: determine the origin & route of transit of radioactive materials used in illegal activities

Reduces illicit trafficking of nuclear materials
Background
Nuclear Fuel Cycle

Conversion to UF₆ → Enrichment → Fuel Fabrication → Nuclear Reactor

Milling → Mining

Storage → Reprocessing
Taggant: A material bearing a unique signature used for the identification of an object or other material

Current Uses

- Electronics
- Radiofrequency identifiers
- Explosives
Isotopes of uranium
- $^{233}\text{U}$ – Storage sites
- $^{236}\text{U}$ – Conversion facilities

Rare earth element mixtures – Mines & fuel fabrication plants
- Varied combinations of lanthanoids

Chemical tracers – Conversion facilities
- Porphyrins
- Phtalocyanines
- Aromatic amines
- Calixerenes
Determine a material that will withstand centrifugal processes to behave as a taggant for $^{235}\text{UF}_6$

- Subject to specific requirements
Possible Applications

- Nuclear forensics
  - Provides a way to track nuclear materials from a specified enrichment plant type
- Safeguards
  - Provides a means of determining the levels of enrichment present within a cascade hall
  - Creates a deterrent against the removal of nuclear material from a centrifugal environment
Requirements

- Same mass as $^{235}\text{UF}_6$ mass (349.03 g/mol)
- Withstand expected conditions subjected to it in a centrifugal environment
- Remain volatile in expected temperatures and pressures subjected to it in a centrifugal environment
  - Centrifuges operate at a minimum vapor pressure of 666.6 Pa at 310 K and within a temperature range of 273-570 K
  - Sublimation point of $^{235}\text{UF}_6$ is 56.5°C
- Not alter enrichment process
- Not negatively impact any of the subsequent fuel cycle processes
- Have a unique signature
- Hard to replicate
Materials Considered

- Dimers
- Molecules
  - $\text{C}_{14}\text{H}_{15}\text{O}_{2}\text{F}_7$
  - $\text{C}_8\text{H}_5\text{F}_{13}$
  - $\text{C}_6\text{F}_{13}\text{NO}$
- Molecules lacking carbon
  - $\text{Si}_5\text{OF}_{10}$
Taggant of Interest

- **Mass:** 347.87 g/mol
  - Requires $^{18}\text{O}$
  - Approximate using $^{234}\text{U}$ with a mass of 348.03 g/mol
- **Hyperfluorinated**
- **Likely volatile within region of interest**
  - $\text{Si}_4\text{F}_{10}$ has a boiling point of 85.1°C
- **Acceptable elemental concentrations for reactor if added at ppm or ppb level**

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F F F F F F F
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Detection Methods

- **Suggested methods:**
  - IR spectroscopy
    - Measures compounds
  - XRF spectroscopy
    - Measures elements

- **Possible alternative methods:**
  - Mass spectrometry
  - Microanalysis
  - Laser-induced breakdown spectroscopy
  - Inductively-coupled plasma spectoscopy
Si$_5$OF$_{10}$ is a theoretically feasible taggant for the centrifugal enrichment process

- Similarity in mass: Yes
- Withstand expected conditions: Maybe
- Remain volatile: Maybe
- Not alter enrichment process: Maybe
- No impact on subsequent processes: Yes
- Unique signature: Yes
- Hard to replicate: No

The compound requires laboratory tests to establish its feasibility as a taggant experimentally
Thank you to Brian Woods & Richard Metcalf for their guidance and support throughout the duration of this project.
I’d like to thank Idaho National Laboratory for hosting me this summer.
This research was performed under the Nuclear Forensics Undergraduate Scholarship Program, which is sponsored by the U.S. Department of Homeland Security Domestic Nuclear Detection Office.
This research was also performed under the Science Undergraduate Laboratory Internship program, which is sponsored by the U.S. Department of Energy.
References

- CRC Handbook of Chemistry and Physics, 91st ed.
- D. Fischer and M. Ryzhinskiy, “Safeguards Environmental Sampling Signatures: Comparison of Two Enrichment Scenarios,” ORNL and IAEA, Oak Ridge and Vienna.
- Thompson, Stephen, and Joe Staley. Chemical Bonding. Fort Collins: Colorado State University. PDF.