Field-deployable mass spectrometer for nuclear safety and security

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Outline

I. Mass spectrometer for nuclear safety and security
II. Field deployable Mass spectrometer
III. Challenges to Field deployment
IV. Overall goal and approach

Mass spectrometer for nuclear security

Nuclear safeguards application

Verification of declared inventories

- Nuclear material sample
- U and Pu isotopic analysis (TIMS*)
- Trace impurities in various matrices (ICP-MS*)

Verification of declared activities

- Environmental sample
- Bulk analysis (TIMS, ICP-MS)
- Particle analysis (TIMS, ICP-MS, SIMS*)

Measurement QA/QC:
"International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials" STR-368 , IAEA

***TIMS Thermal ionization mass spectrometer**
ICP-MS Inductively coupled plasma mass spectrometer
SIMS Secondary ion mass spectrometer

Mass spectrometer for nuclear security

Nuclear forensics application

Parameter	Information
U and Pu content	Chemical composition, fuel type, weapon type
U and Pu Isotope ratio	Enrichment level, intended use, reactor type, fuel type, weapon type
Trace Impurities	Production process, geolocation
Age	Production date

Timeline for a nuclear forensic investigation

Technique	24 -hours	1- week	1- Month
Isotope analysis	alpha-spectroscopy gamma-spectroscopy	Mass spectrometry (TIMS, ICP-MS, SIMS)	Radiochemical separations

Mass spectrometer for nuclear safety

Emergency response: Accidental ingestion, inhalation of nuclear material

Internal dosimetry:

- *in-vivo* bioassay (direct measurement of radioactivity in the body)
- *in-vitro* bioassay (measurement of radioactivity in a person's urine or feces)

Demand:

- Rapid, accurate and sensitive determination of long-lived actinides (U, Th, Pu) in sample (TIMS, ICP-MS, Alpha spectrometry)

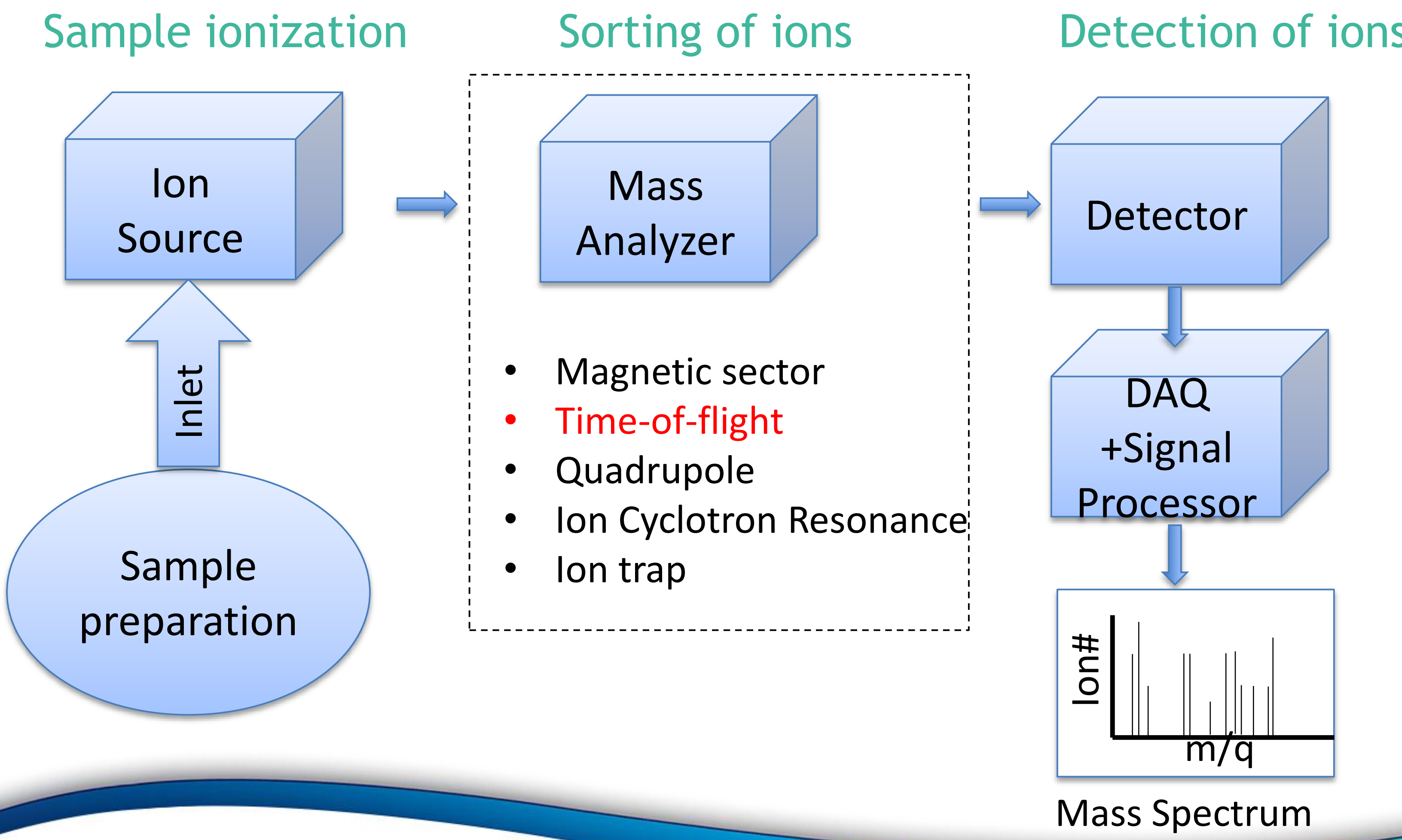
Challenges:

- High sensitivity- 1 femtogram of actinide/ 1 liter urine sample

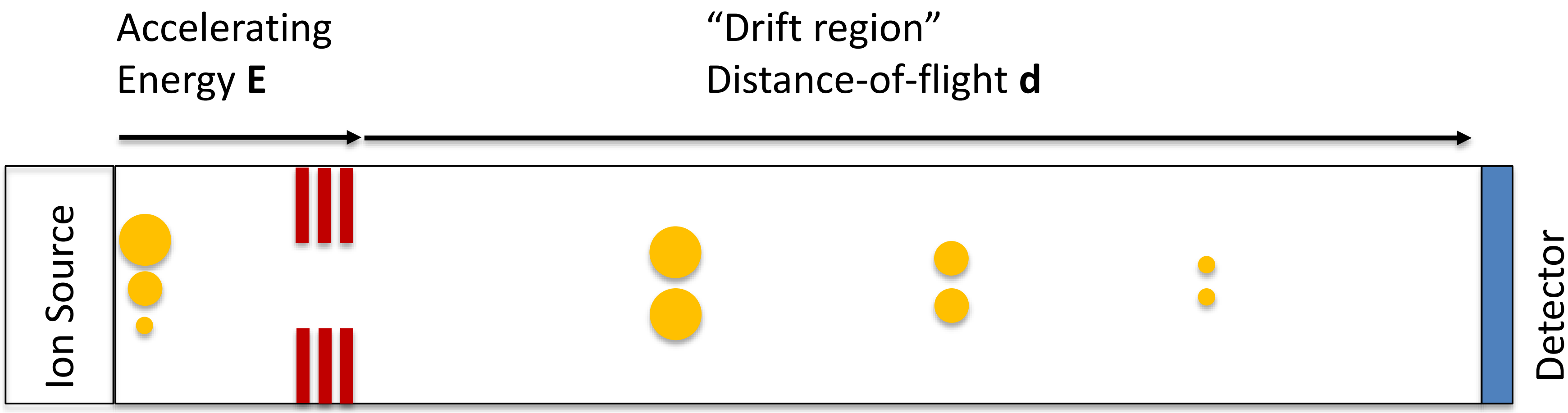
Field-deployable MS instruments

- Current practice
  - Sample collected from nuclear facilities and shipped to laboratory for destructive analysis (DA)
- Field-deployable mass spectrometer
  - Near-real time knowledge
  - Eliminate or reduce shipment of hazardous material
- Ideal goal
  - Would meet the International Target Values (ITV) set for laboratory DA
- Reasonable goal
  - Improve the accuracy currently achieved by in-field NDA

Mass Spectrometer



Time-of-flight (TOF) MS



$$m = \left(\frac{2E}{d^2}\right) t^2$$

$$R = \frac{m}{\Delta m} = \frac{t}{2\Delta t}$$

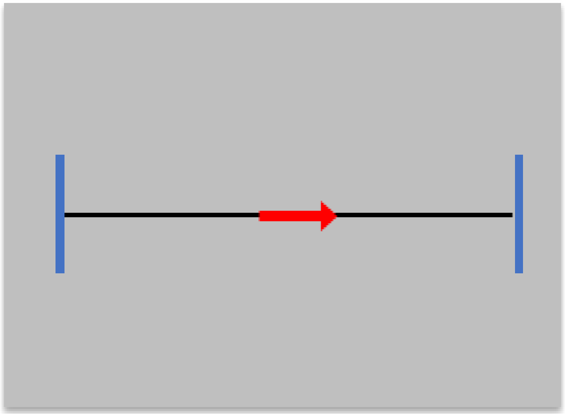
Advantage

- Simplicity
- Ruggedness
- Unlimited mass range
- Rapid data acquisition

Disadvantage

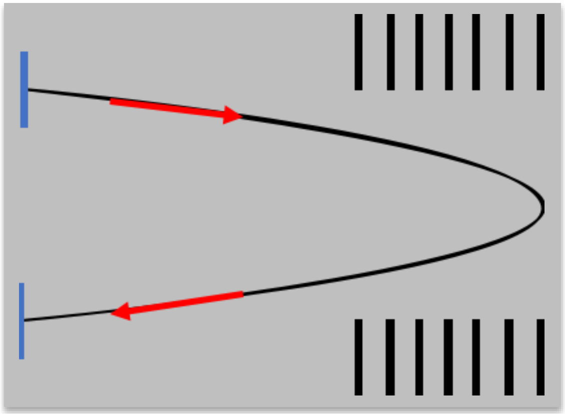
- require longer 'd'

Schemes for increasing TOF length



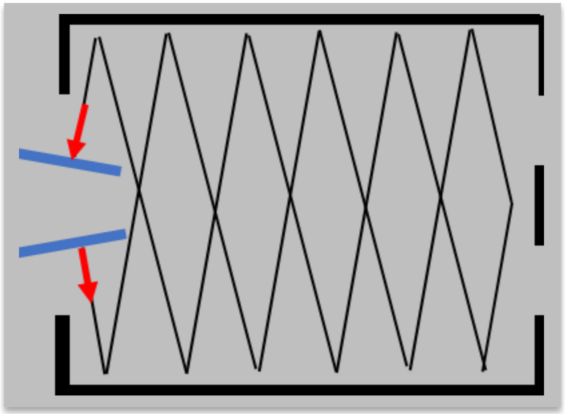
Linear TOF MS

Cameron and Eggers (1948)



Ion Mirror TOF MS

Mamyrin (1973)

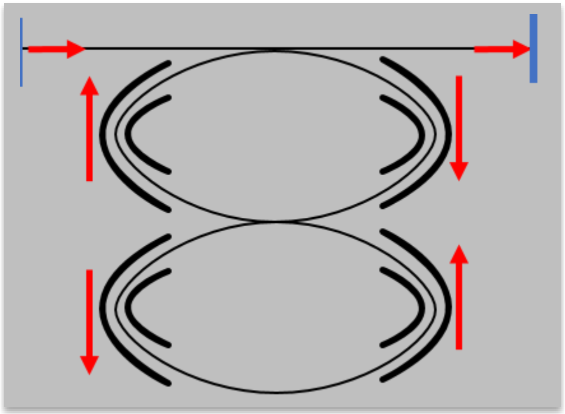


Planar multi-reflection TOF MS

Verenchikov(2004)

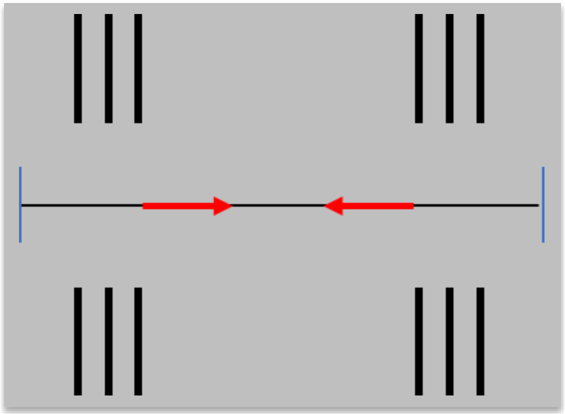
Schemes for increasing TOF length

Multiple-pass TOF MS



Multi-turn electrostatic sector TOF MS

Toyoda (2003)



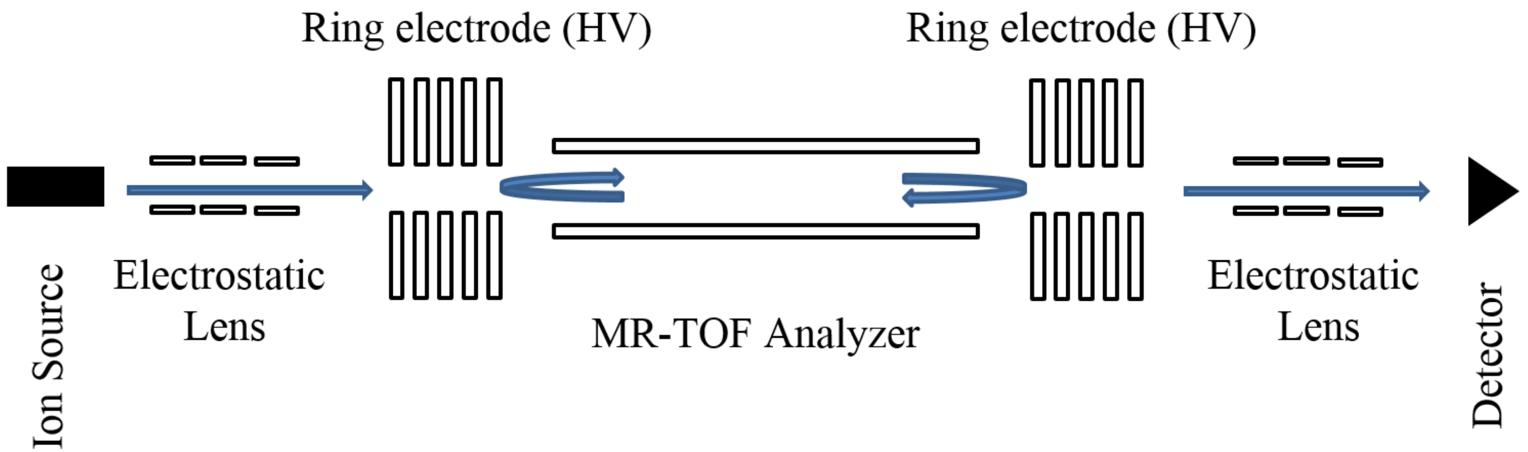
Multi-reflection TOF MS

Wollnik and Przelowka (1990)

Radioactive isotopes measured (ISOLDE/CERN)

Wienholtz et al., Nature (2013)

Multi Reflection Time of Flight MS



- TOF length ~ 1 m
- Mass resolving power (FWHM) ≥100,000

$$R = \frac{m}{\Delta m} = \frac{t}{2\Delta t} = \frac{nT}{2\sqrt{\Delta t_0{}^2 + n^2 \Delta T^2}}$$

Challenges to MS field-deployment

- Sample preparation
  - Rapid in-field sample preparation to fully exploit fieldable MS system
- Ion source
  - No or minimum sample preparation requirement
  - Atmospheric pressure ionization
- Mass Spectrometer
  - No portable commercial off-the-shelf (COTS) MS system for elemental or isotopic analysis

Market Research Survey of Commercial Off-The-Shelf (COTS) Portable MS Systems for IAEA Safeguards Applications Pacific Northwest National Laboratory (PNNL-22237) 2013
FY15 update, Los Alamos National Laboratory (LA-UR-15-28831) 2015

Path forward

- Overall goal

I. Develop simple sample preparation and ionization technique for in-field use

II. Adapt to small COTS MS system or 'customized' MS system

- Approach

I. Laser ablation ion source looks promising, can eliminate sample preparation for certain sample types.

II. A compact Multi-turn TOF MS is in market, development in Multi-reflection TOF MS is promising and progressing.

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Thank you.

Questions?

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