Evaluation of Small Mass Spectrometer Systems

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Introduction

Understand Aspects of Designing a
Miniature Mass Spectrometer (MS) System

Systems Evaluated

- Linear Quadrupole
- Quadrupole Array
- Quadrupole Ion Trap
- Time of Flight
- Sector

Figures of Merit

- Accuracy
- Precision
- Limits of Detection
- Scan Rate
- Response Time
- Recovery Time
- Volume
- Weight

Set Up Scale to Rank Systems

Why Miniaturize?

- Improve Portability
  - Field Applications
  - Real-Time Analysis
  - Decrease Contamination
- Size Reduction
  - Increase Sensor Density
  - Less Intrusive
- Cost Reduction
  - Less Weight
  - Less Power

Potential Applications

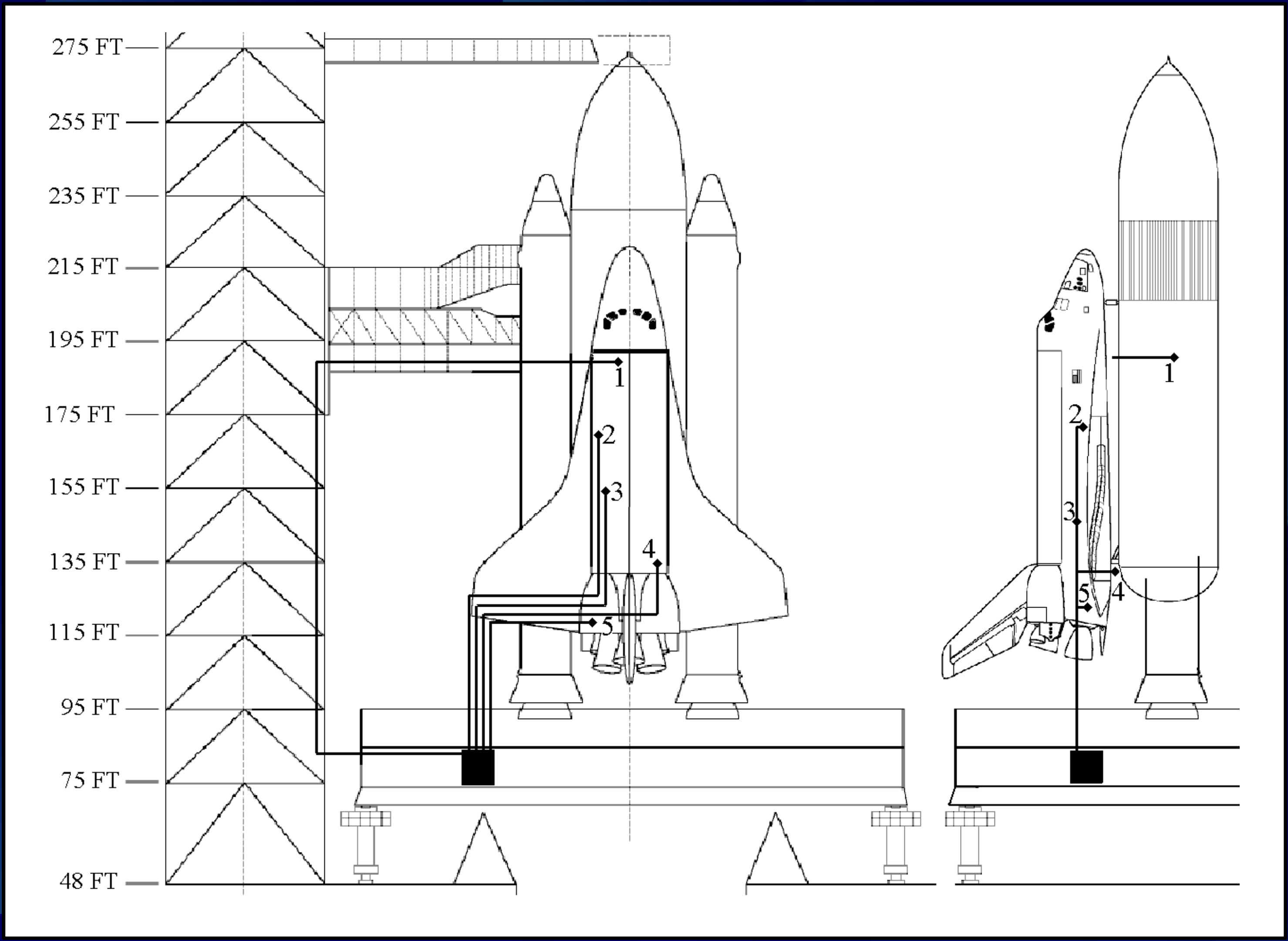
- Leak Detection
  - Hazardous Gases
  - Helium
  - Refrigerants
- Air Analysis
  - Worker Safety
  - Public Safety
  - Chemical Weapons
- Law Enforcement
  - Contraband Detection
- Field Medical Analysis
- Process Control
  - Semiconductors
  - Hydrogen Economy

NASA Applications

- Next-Generation Leak Detection During
  - Processing
  - Cryogenic Fueling
  - Launch Countdown
- Shuttle Engine Monitoring
- Air Analysis
  - International Space Station Air Lock
  - Shuttle Air Lock
- Process Control
  - Martian Fuel Generators

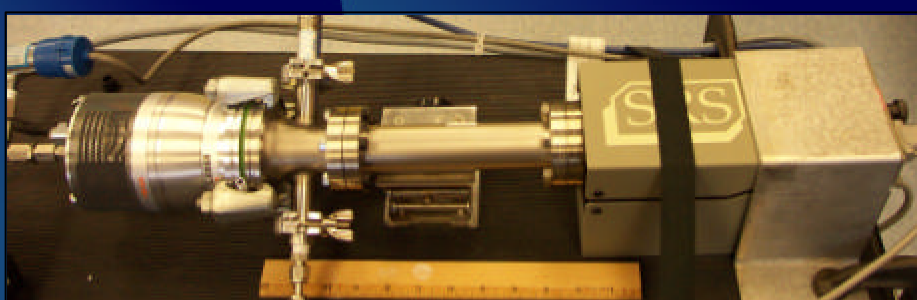
Current Problems

Response Time | Scan Rate | Sampling Density



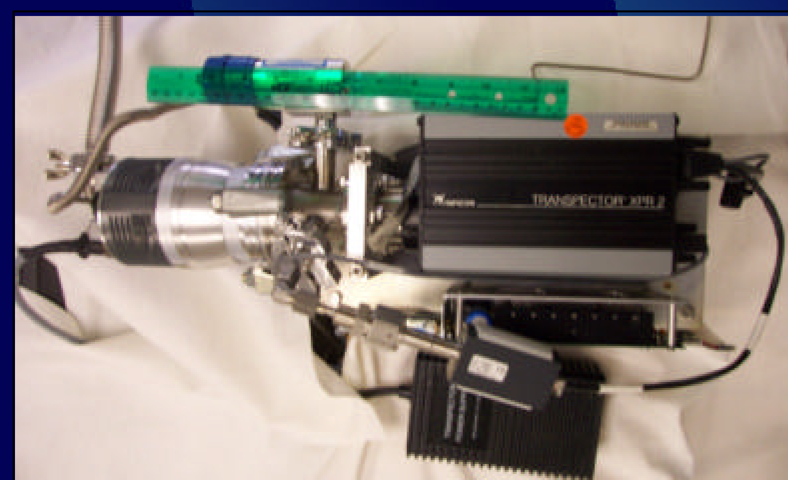
Stanford Research Systems (SRS) RGA-100

- Linear Quadrupole Analyzer
  - Cylindrical Rods: 6.35mm OD
  - Rod Length: 11.4 cm
  - Inscribed Radius: 2.77 mm
  - Frequency: 2.76 MHz
- Pressure = 5 x 10^{-5} torr



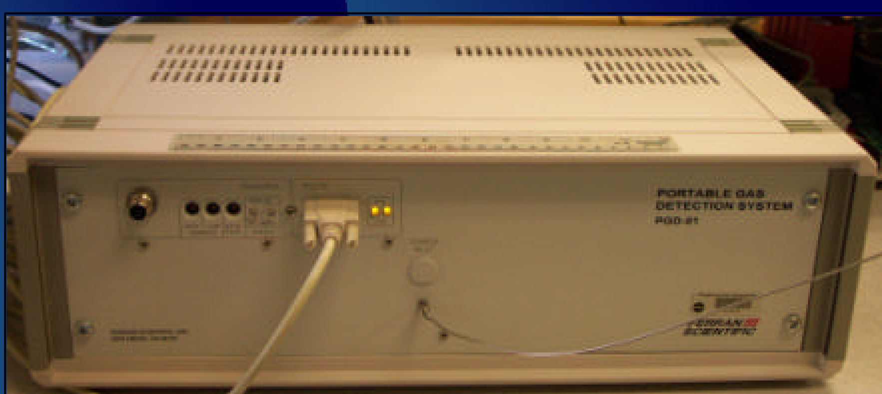
Inficon XPR-2

- Linear Quadrupole Analyzer
  - Hyperbolic Rods
  - Rod Length: 12.7 mm
  - Inscribed Radius: 0.33 mm
  - Frequency: 13 MHz
- Pressure = 1 x 10^{-4} torr



Ferran

- Quadrupole Array System
  - 16 Cylindrical Rods: 1 mm OD
  - Rod Length: 10 mm
  - Frequency = 16 MHz
- Pressure: 5×10^{-4} torr



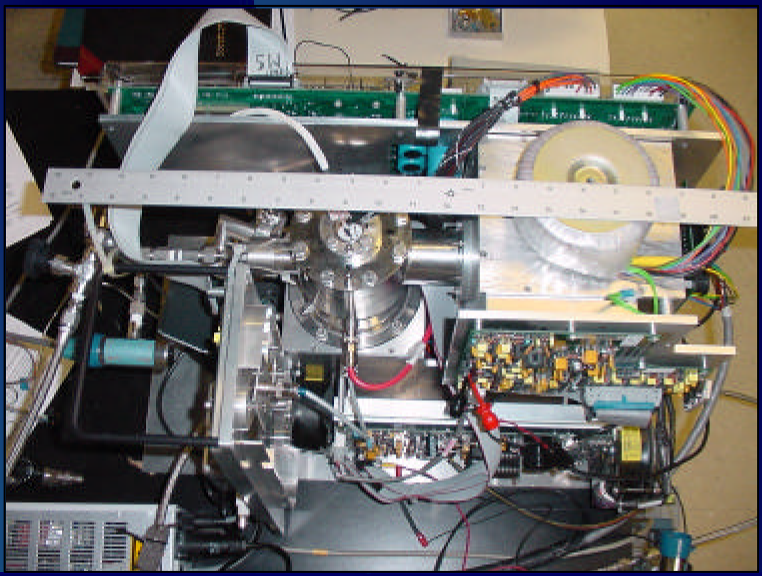
IonWerks Time-of-Flight (TOF)

- Reflectron TOF System
  - Orthogonal Acceleration
  - Extraction Pulse: 600 V
  - Sampling Rate: 50 kHz
- Pressure: 5×10^{-6} torr

University of Florida Ion Trap (UF-IT)

- Quadrupole Ion Trap System

  Ring Radius: 10 mm
  Stretched Geometry
  Frequency = 2.5 MHz
  No Buffer Gas
- Pressure: 4 x 10^{-6} torr



Thermo Finnigan Polaris-Q

- Quadrupole Ion Trap System

  Ring Radius: 7 mm
  Stretched Geometry
  Frequency = 1.03 MHz
  Helium Buffer Gas
- Pressure: 1 x 10^{-3} (4 x 10^{-6}) torr

Monitor Group
MG-2100

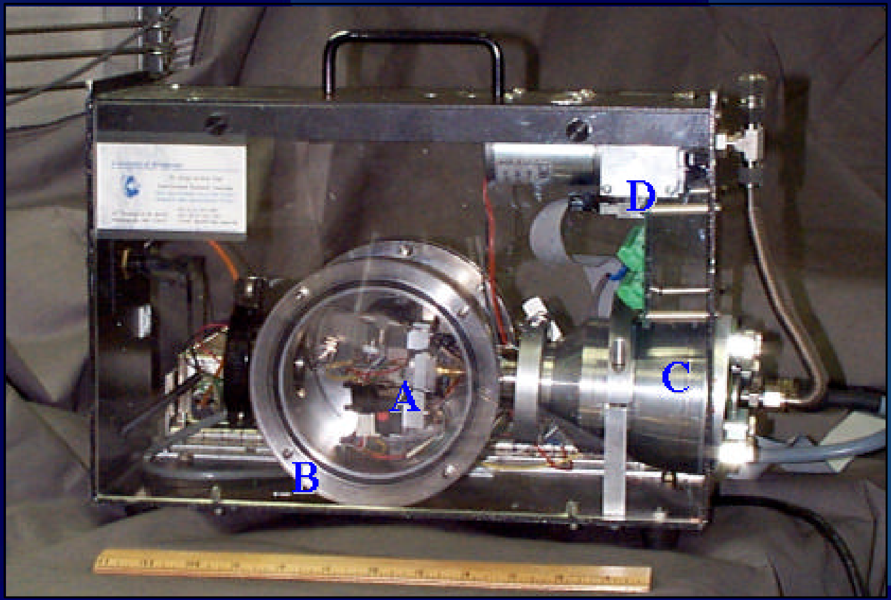
- Cycloidal Sector System
  B: 0.5 tesla
  Pitch: 1 inch

- Pressure: 5 x 10^{-6} torr

University of Minnesota
Compact Double Focus MS (CDFMS)

- Double Focus Sector System
  B: 0.75 tesla
  Sector Radius: 20 mm

- Pressure: 10^{-5} torr



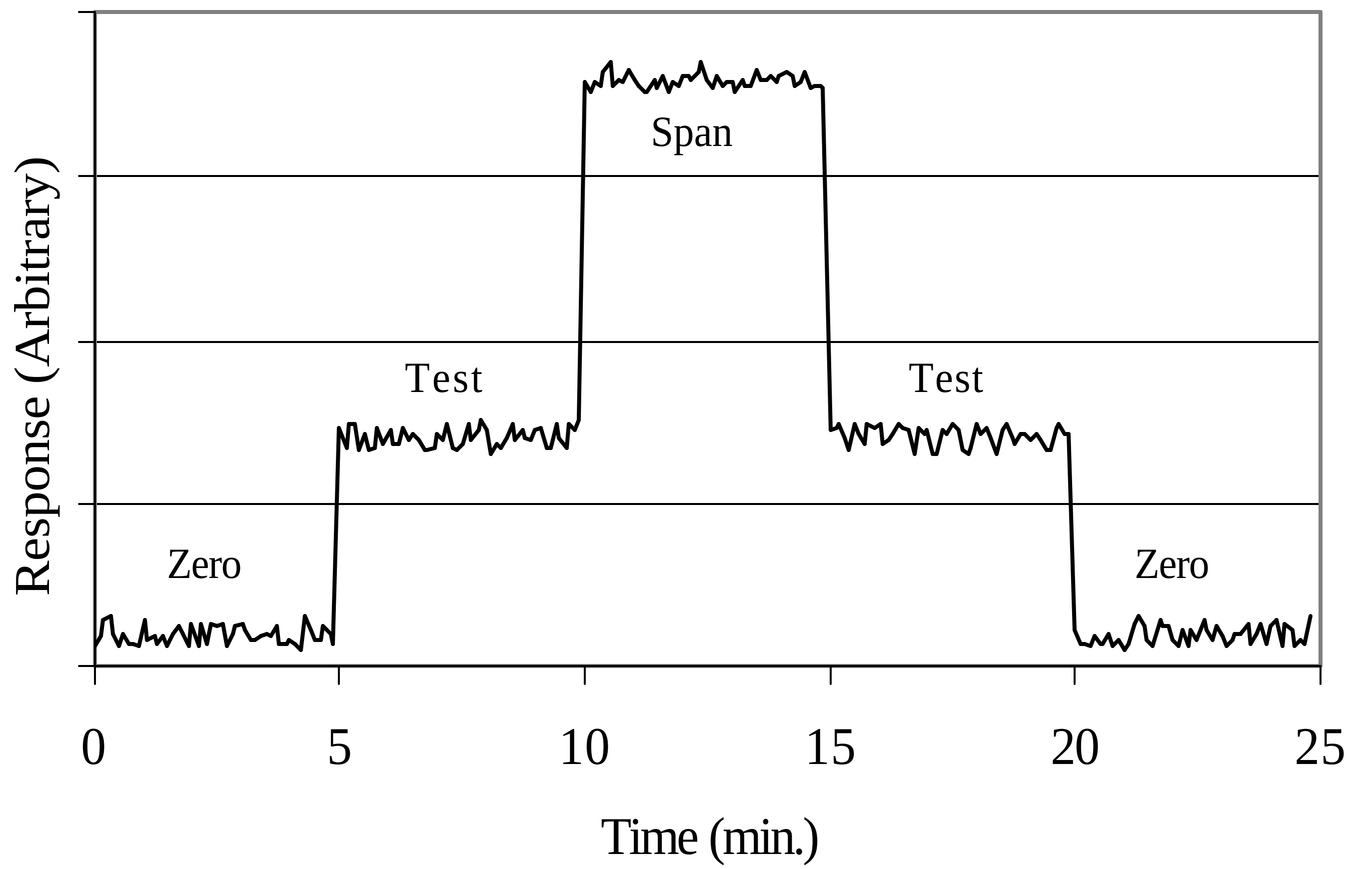
Experimental Parameters

Parameter	Definition	Shuttle Requirement
Accuracy	$\frac{[Test]_{meas} - [Test]_{true}}{[Test]_{true}} \times 100\%$	< 10% or 5 ppm, whichever is greater
Precision	$\frac{\sigma_{Test,meas}}{[Test]_{meas}} \times 100\%$	< 5% or 3 ppm, whichever is greater
Limit of Detection	$3\sigma_{zero}$ [a]	H_2, O_2: 25 ppm; He: 100 ppm; Ar: 10 ppm[b]
Response Time	Time required for response from valve change to 95% new reading	10 s
Recovery Time	Time after valve change to reach 5% of previous sample reading (new sample is zero)	30 s
Scan Rate	Experiment time / scans	1 s
System Volume	Sum of individual components	3.5×10^4 cm^3
System Weight	Sum of individual components	10 kg

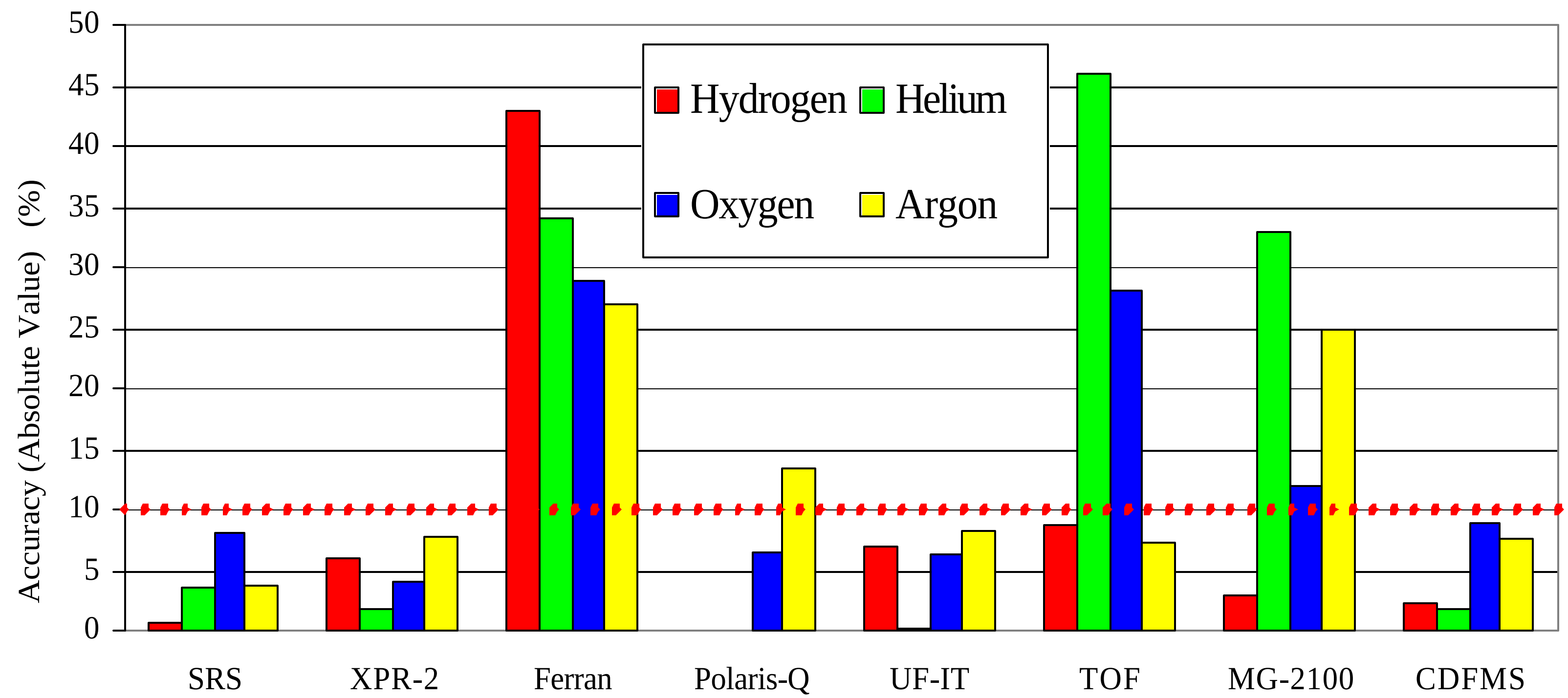
[a] Theoretical limit of detection

[b] Measured limit of detection

Experimental Scan

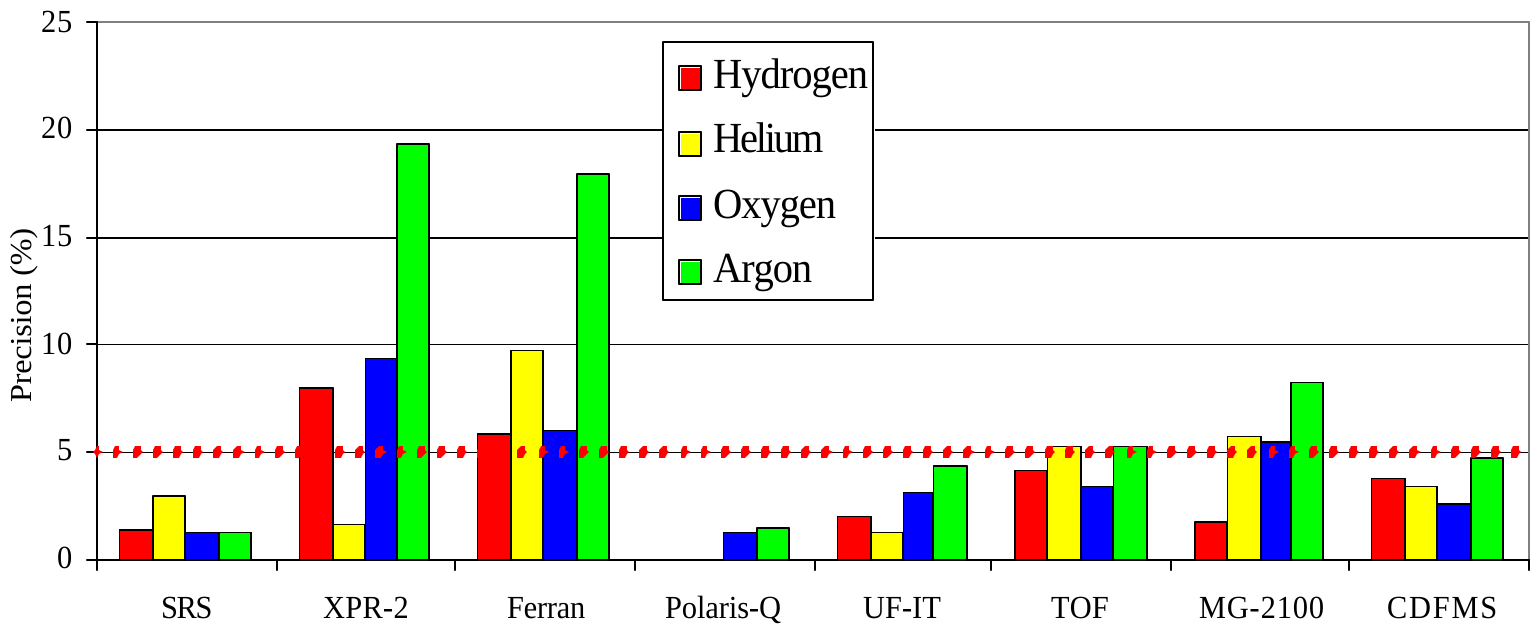


Accuracy



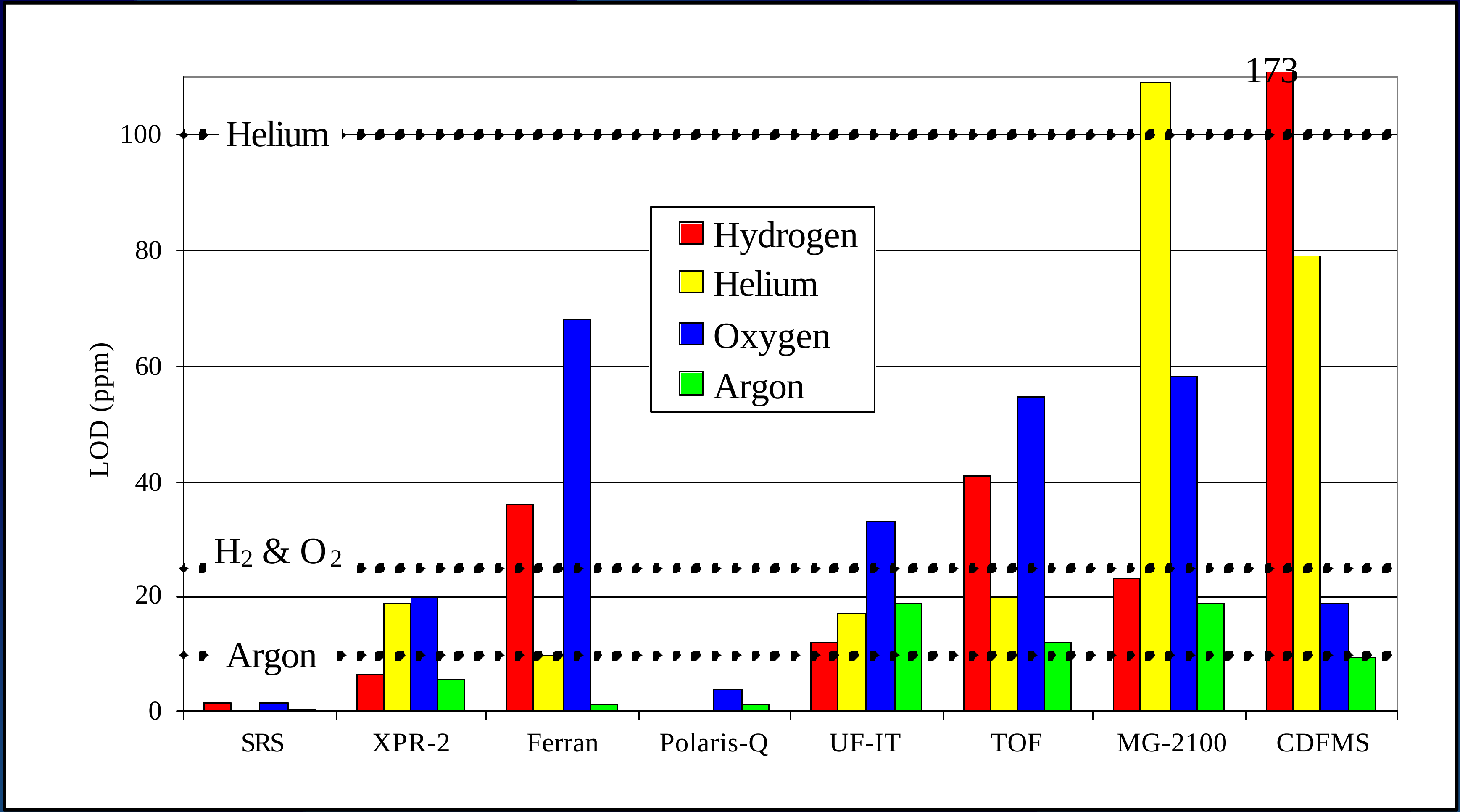
Accuracy (Absolute Value) (%)
50
45
40
35
30
25
20
15
10
5
0
Hydrogen
Helium
Oxygen
Argon
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

Precision

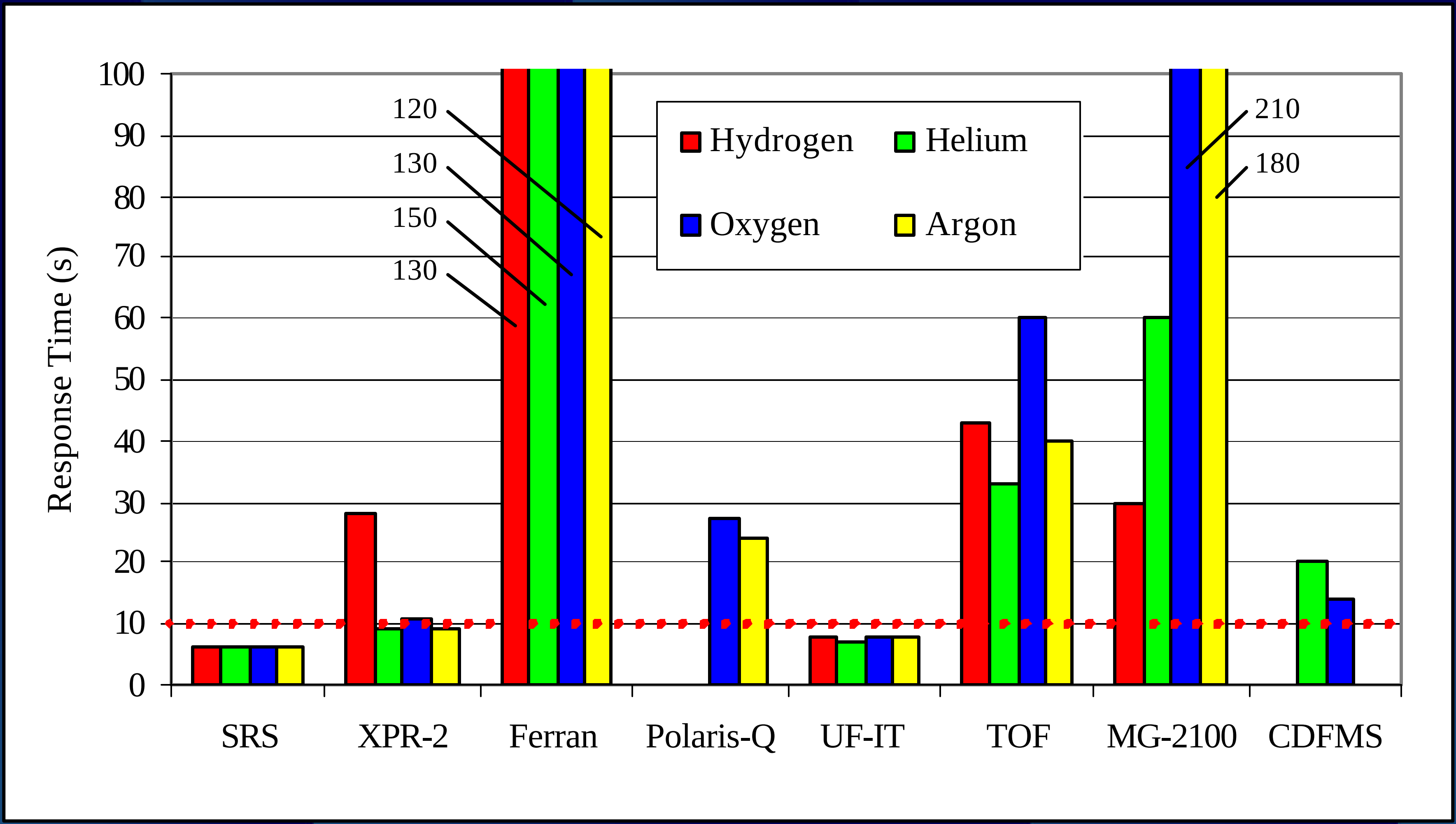


Precision (%)
25
20
15
10
5
0
Hydrogen
Helium
Oxygen
Argon
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

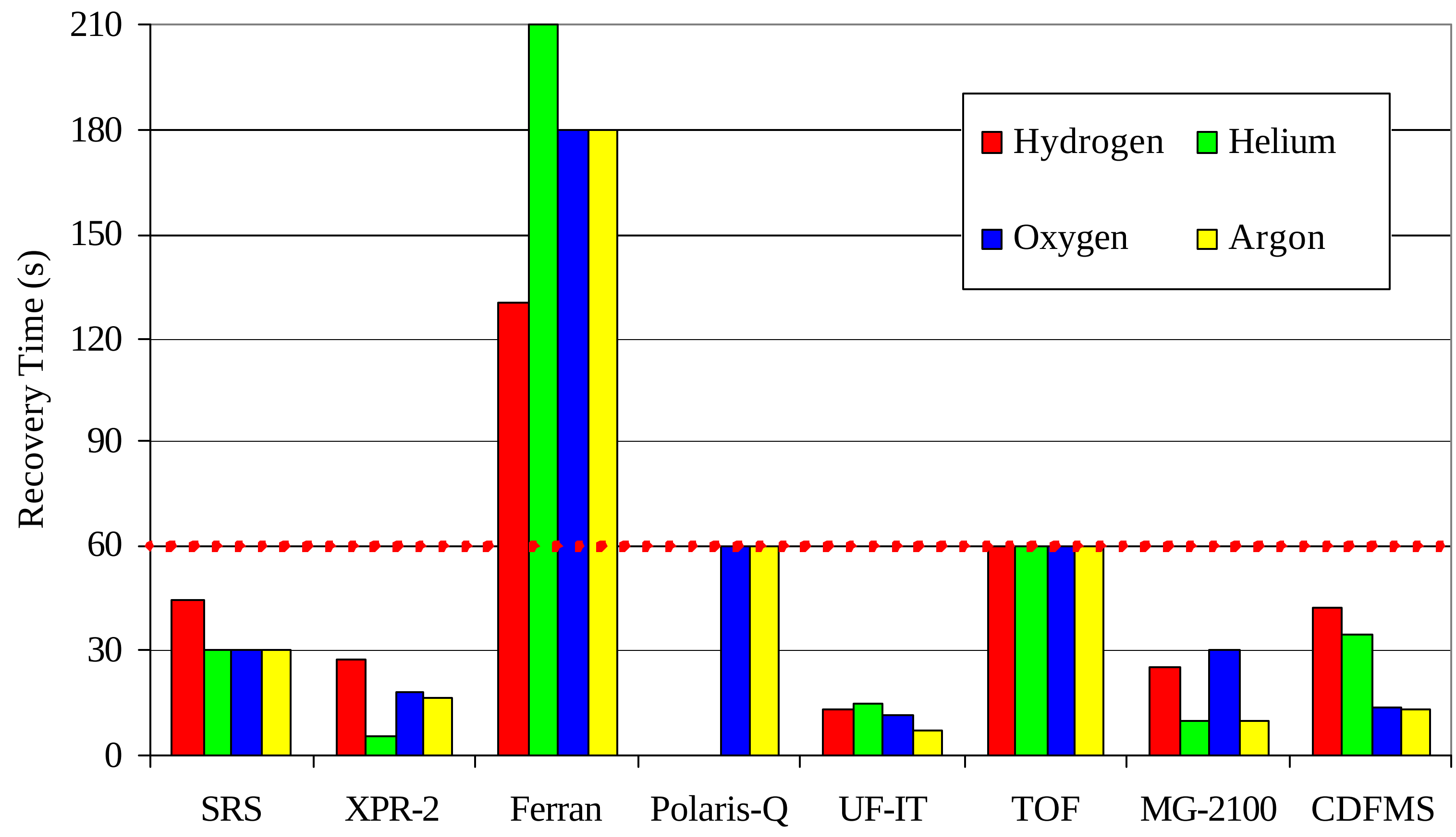
Limits of Detection (LOD)



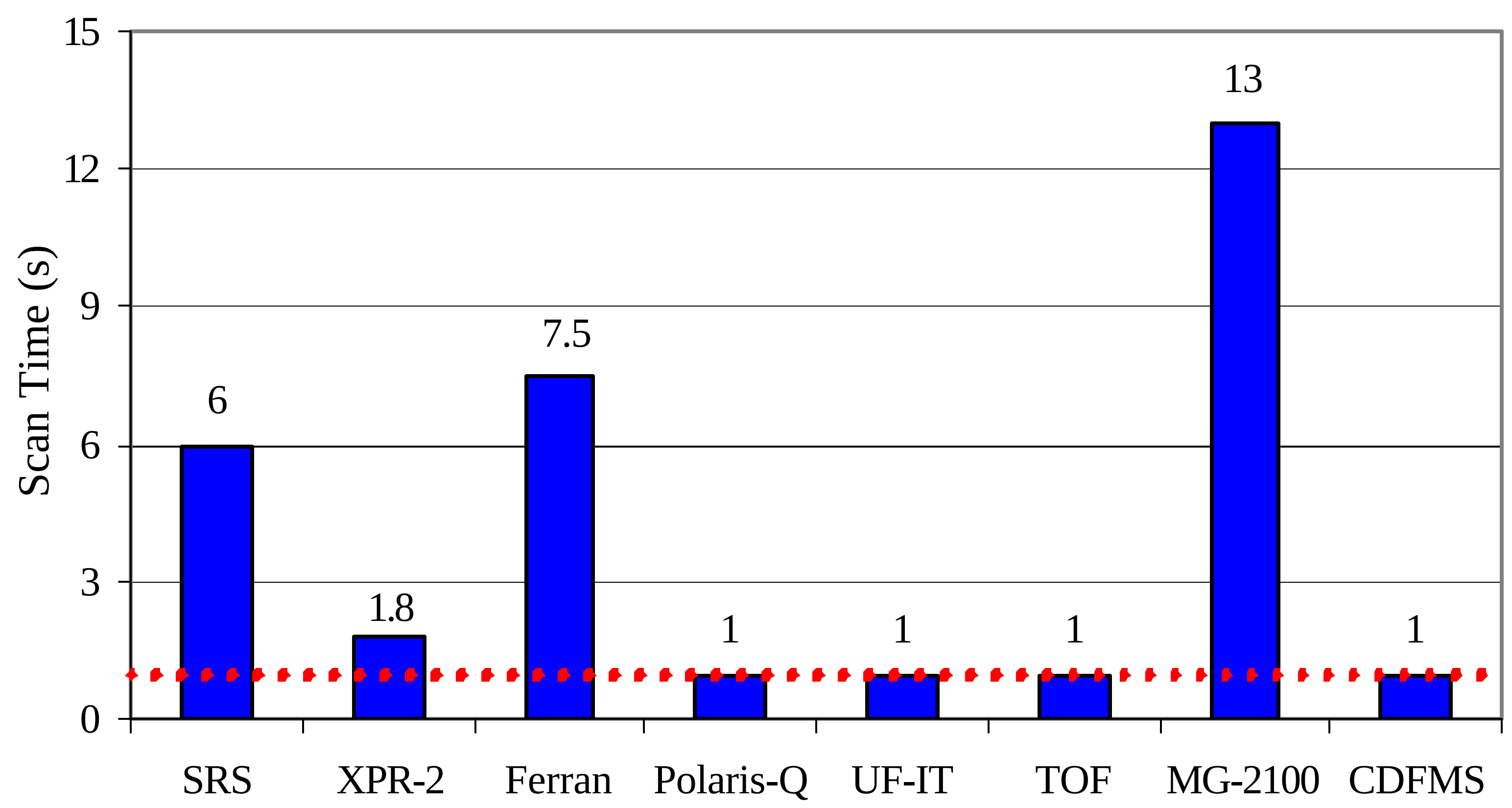
Response Time



Recovery Time

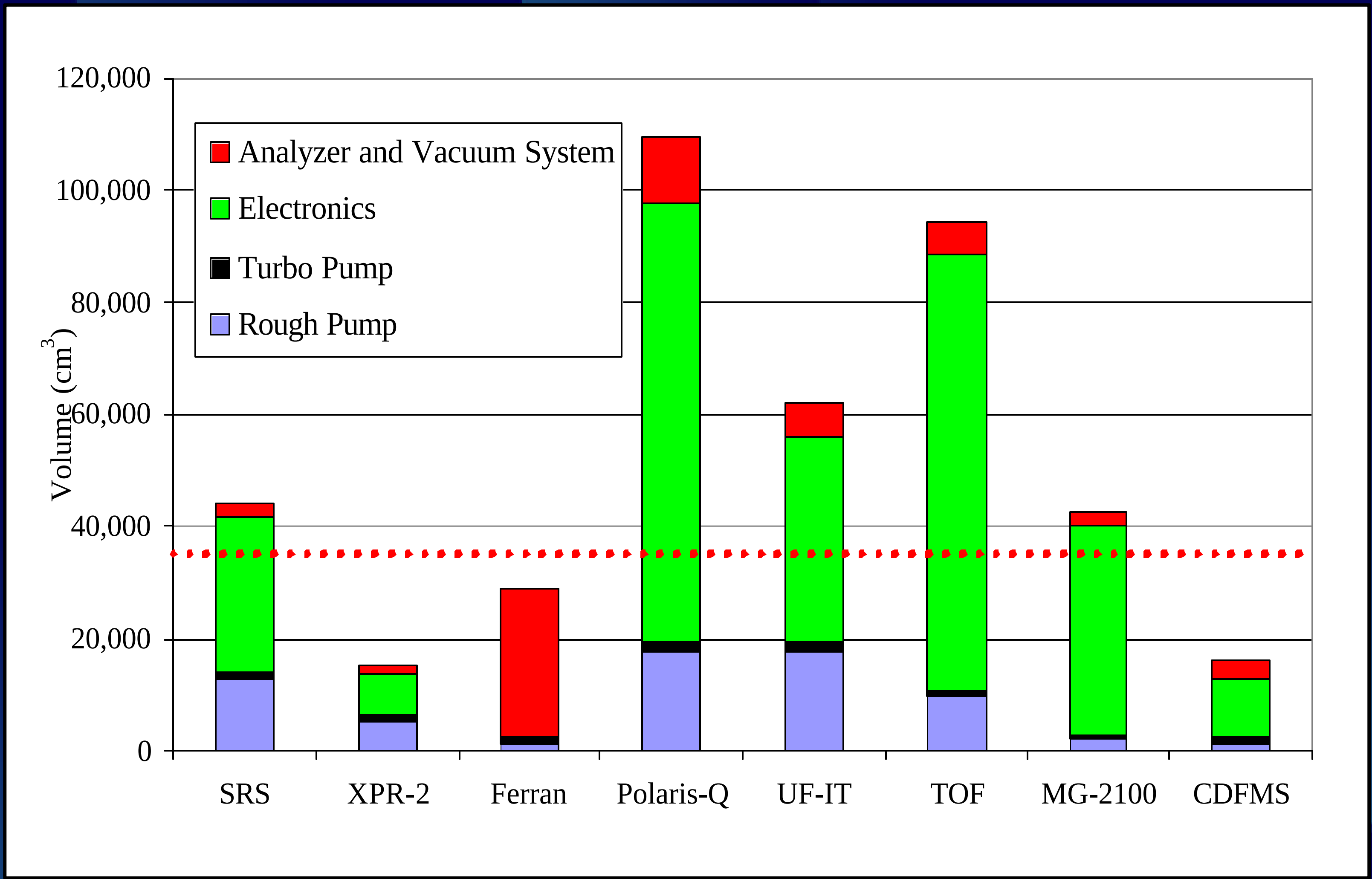


Scan Time

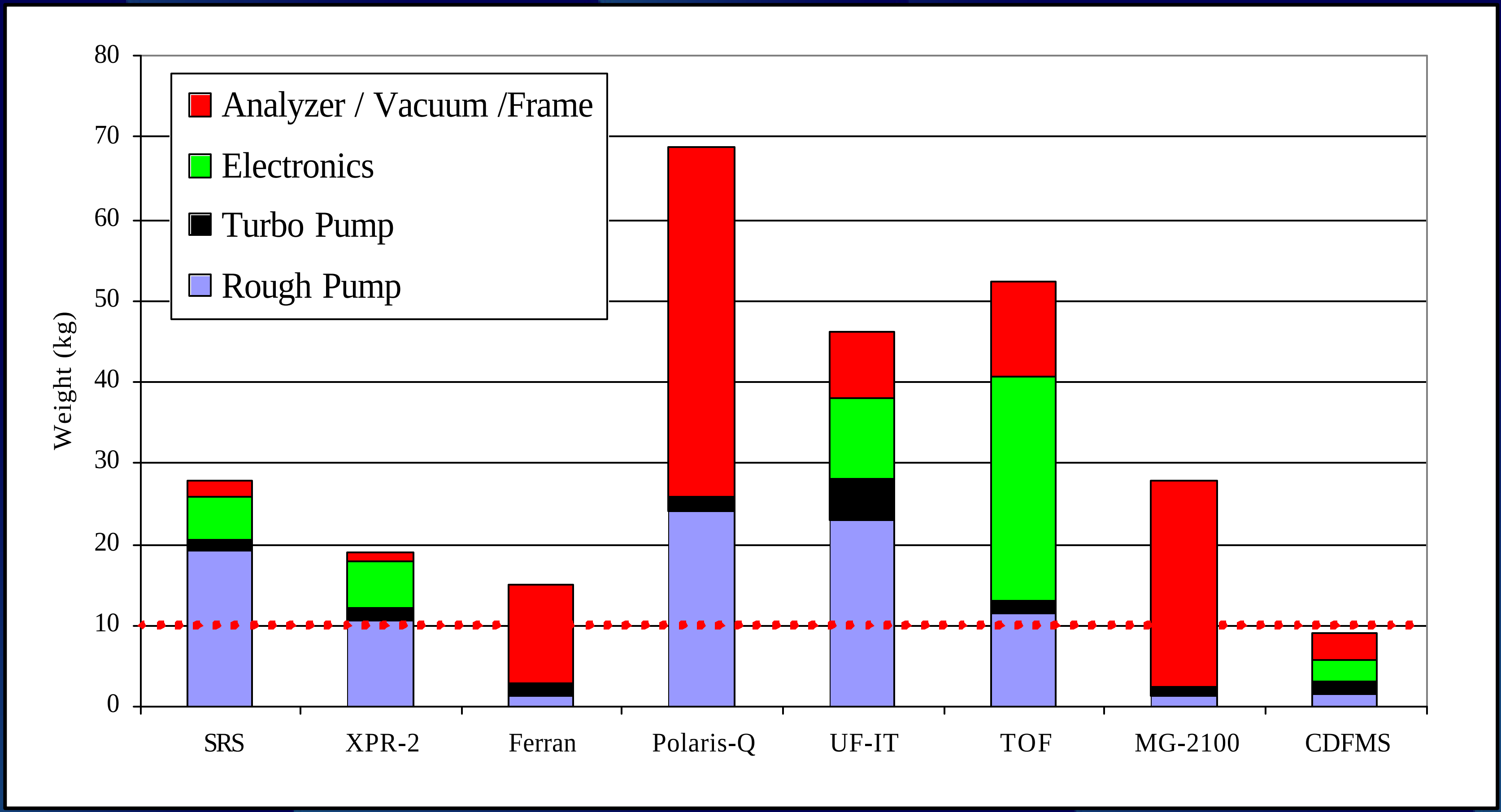


15
12
9
6
3
0
Scan Time (s)
6
1.8
7.5
1
1
1
13
1
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

System Volume



System Weight



Evaluation Chart

	Accuracy	Precision	LOD	Response	Recovery	Scan Rate	System Volume	System Weight	Score
SRS	2	2	1	2	6	8	6	7	**4.3**
XPR-2	3	8	2	7	5	5	2	6	**4.8**
Ferran	10	10	7	10	10	9	3	6	**8.1**
Polaris-Q	7	3	2	8	8	2	10	10	**6.3**
UF-IT	3	3	6	3	3	2	7	8	**4.4**
TOF	9	6	7	9	7	2	9	8	**7.1**
MG-2100	9	7	10	10	5	10	6	7	**8.0**
CDFMS	4	5	9	8	6	2	2	4	**5.0**
Average[1]	**4.7**	**4.5**	**4.5**	**6.2**	**5.8**	**3.5**	**6.0**	**7.1**	

[1]Excluding Ferran and MG-2100

Conclusions

- Various Mass Analyzer Systems Evaluated

- Several Systems Show Promise
  - Stanford Research Systems RGA-100
  - Inficon XPR-2
  - University of Florida – Ion Trap
  - Compact Double Focus Mass Spectrometer

- Areas That Need Improvement
  - Response Time
  - Recovery Time
  - System Volume
  - System Weight

- Future Work
  - Investigate Techniques To Improve Systems
  - Evaluate Engineering Challenges