Detection of Clandestine Centrifuge Enrichment

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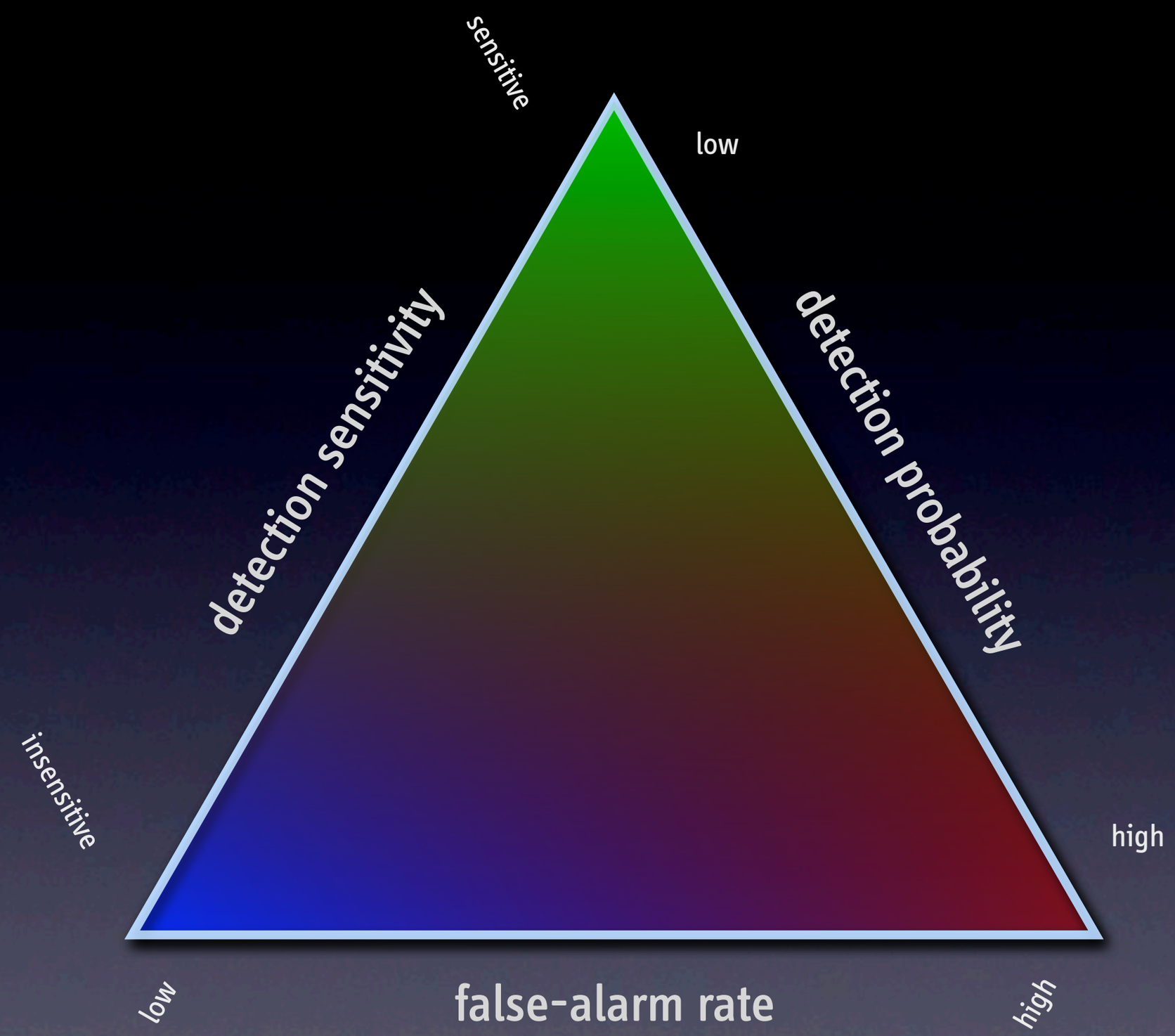
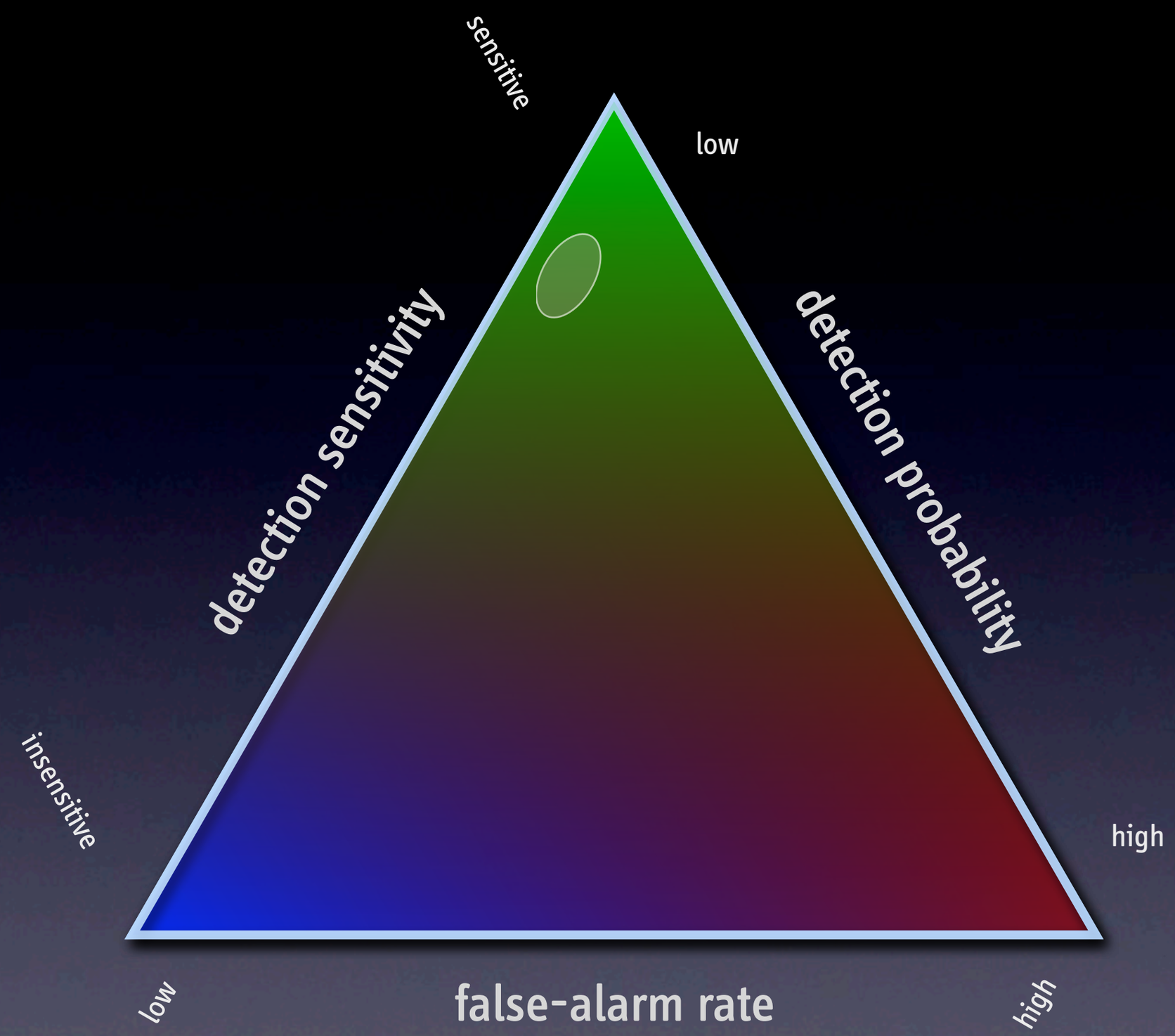
American Physical Society panel on Technical Steps to Support Verifiable Nuclear Arsenal Downsizing - 22 April 2009 - Washington DC


sensitive
low
detection sensitivity
detection probability
insensitive
high
low
false-alarm rate
high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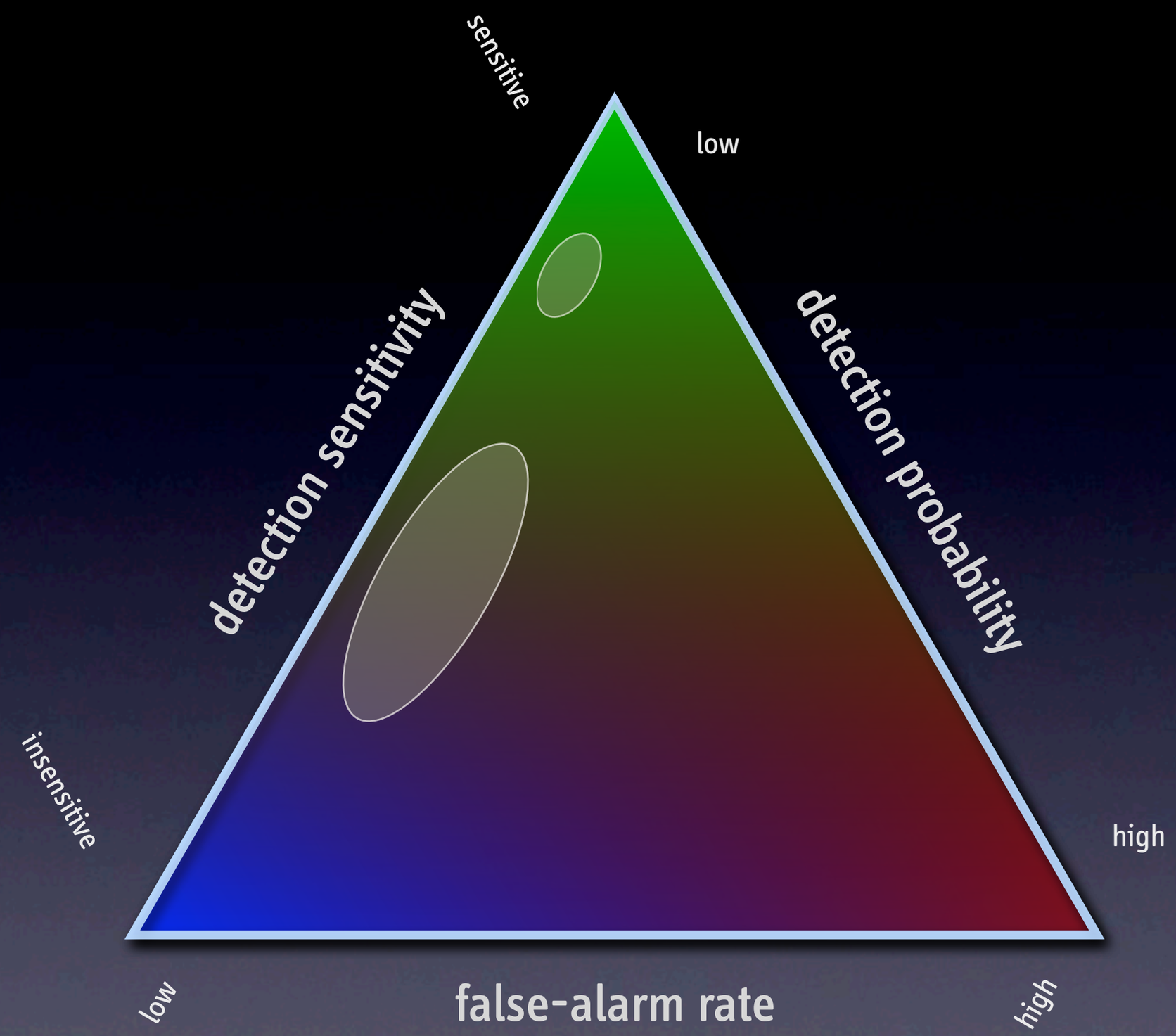


political goals may permit a relaxation of constraints

External Constraints

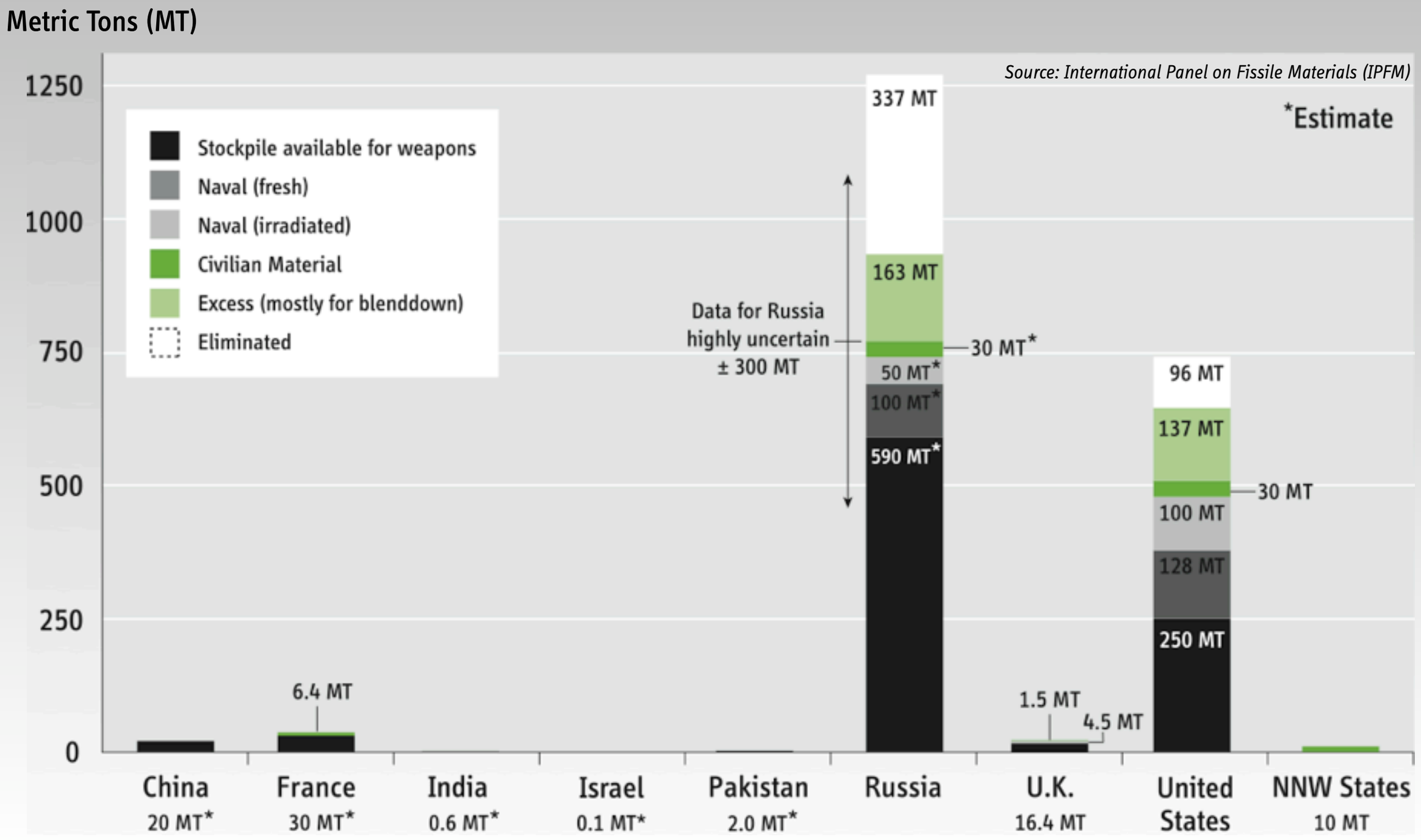
Ability to verify HEU stockpiles, esp. Navel stocks

Measurement uncertainties in reprocessing plants

1% of all Pu throughput (= 80 kg at Rokkosho) or 10% of Pu in MOX, whichever is greater

Other uncertainties (e.g., dismantlement)

HEU Stocks Significant



The Means of Detection

A partial list ?

Optical	photography
	thermal Infrared
Effluent	HF gas
	UO_2F_2 aerosols
Electromagnetic	ULF radio
	atomic magnetometer
	line notching
	power waveform distortion
	ULF on transmission lines


60
meters
0
60

Effluents

$$UF_6 + 2\ H_2O \longrightarrow UO_2F_2 + 4\ HF$$

UO_2F_2 Aerosol Characteristics

Release Scenario	Size	V_{dep}*
Routine	0.01-1 μm	~2 m/day
Massive Spill	1-2 μm	~50 m/day

* all calculations assume effective deposition velocity of 86 m/day (0.1 cm/s)

Source: R.S. Kemp "Initial analysis of the detectability of UO2F2 aerosols produced by UF6 release from uranium conversion plants," Science & Global Security, 16:3 (2008).

Source Terms

Type	Facility	Emissions Rate 95% CI [gUF6/tHM-Unat]	Emissions for 1 MT HEU/yr [gUF6/day]
Centrifuge	Capenhurst	0.0010 - 0.0023 n=194	0.0013

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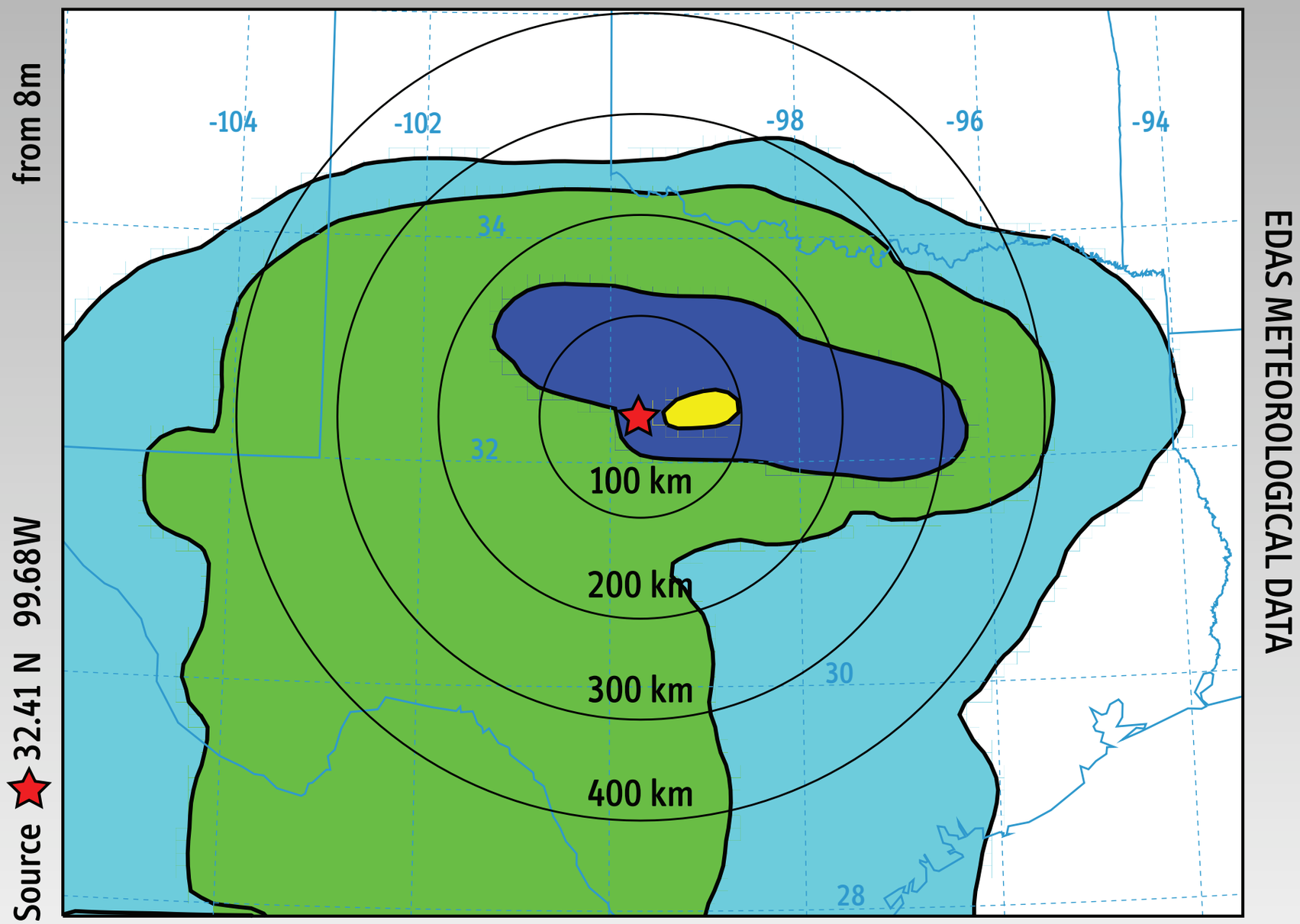
Centrifuge	Capenhurst	0.0010 - 0.0023 n=194	0.0013
Conversion	Honeywell Metropolis	13.4 - 19.5 n=7	11.3
	Cameco Port Hope	3.0 - 4.3 n=20	0.13
	Comurhex Pierrelatte	0.01 - 0.04 n=3	0.0082

Port Hope Scenario
NOAA HYSPLIT MODEL

Concentration ($\mu g/m^3$ UO_2F_2) averaged between 0m and 100m
Integrated from 1200 18 Jan to 0000 19 Jan 03 (UTC)
Continuous UF_6 release started at 1200 02 Jan 03 (UTC)



$1x10^{-8}$	$1x10^{-9}$	$1x10^{-10}$	$1x10^{-11}$	$\mu g/m^3$
0.01 ppb	0.001 ppb	0.1 ppt	0.01 ppt	city aerosol sampling
0.3 ppb	0.03 ppb	3 ppt	0.3 ppt	rural aerosol sampling

ULF Radio

Ultra Low Frequency = 300 - 3000 Hz

power supply driving frequency

$$\nu = \frac{pv_p}{2\phi\pi D}$$

350 - 1500 Hz

λ = 200 - 850 km

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near-field dipole magnetic field (r << λ/2π)

$$B_{\text{dipole}} = \frac{\mu_o I_o b^2}{4\pi}\frac{1}{r^3}(2\cos\theta \quad \hat{r} + \sin\theta \quad \hat{\theta})$$

$$B_{\max} = \frac{2\mu_o I_o b^2}{4\pi}\frac{1}{r^3} n_t\, n_c$$

ULF Radio

near-field dipole magnetic field

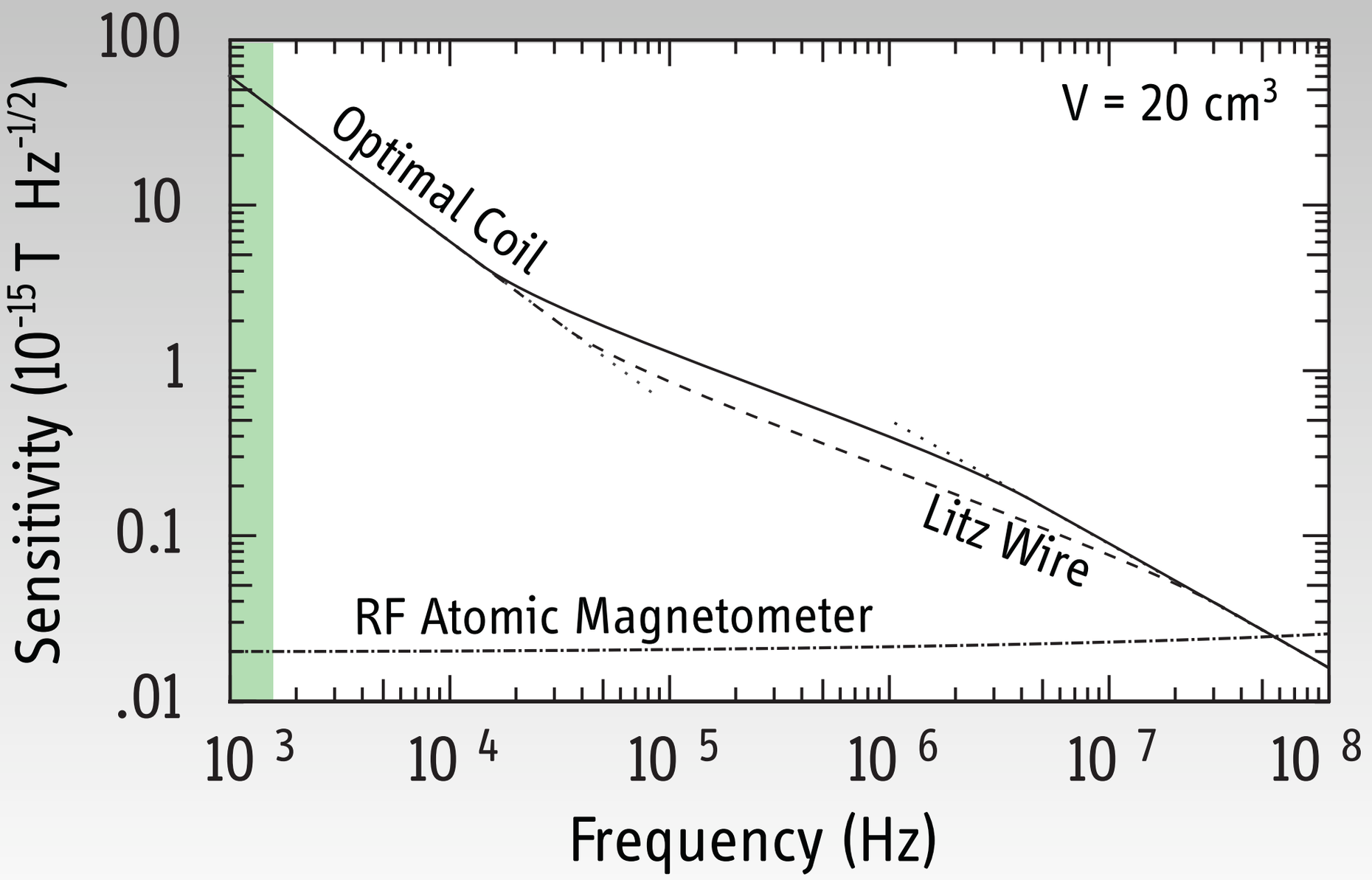
$$B_{\max} = \frac{2\mu_o I_o b^2}{4\pi} \frac{1}{r^3} n_t \, n_c$$

A set of generous assumptions

$$\begin{aligned} I_o &= 1\,\mathrm{Amp} \\ b^2 &= 100\,\mathrm{cm}^2 \\ n_t &= 1000\,\mathrm{turns} \\ n_c &= 2000\,\mathrm{machines} \end{aligned}$$

$$B_{\max} = \frac{4 \times 10^{-3}}{r^3} \quad \mathrm{Tesla}$$

Atomic Magnetometer



Source: I.M. Savukov, et. al., "Tunable atomic magnetometers for detection of radio-frequency magnetic fields," Phys. Rev. Let., 95:063004 (2005)

ULF Radio

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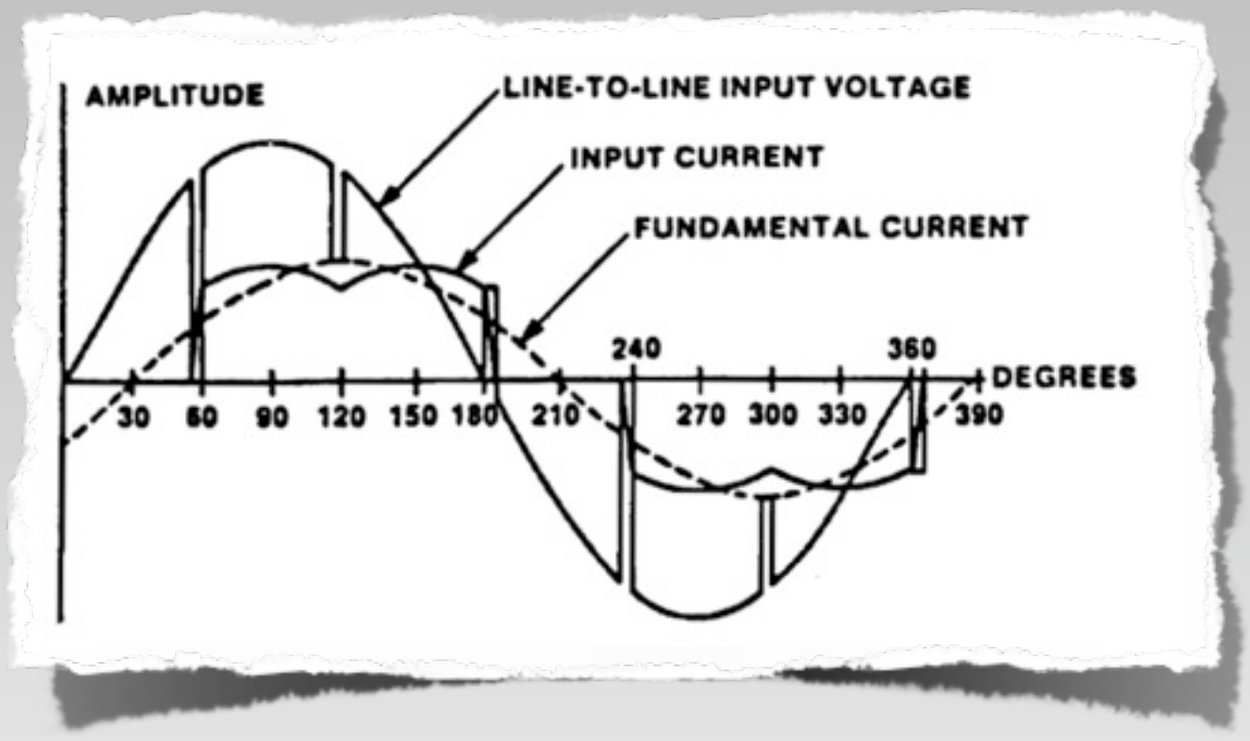
$$B_{\max} = \frac{4 \times 10^{-3}}{r^3} \quad \mathrm{Tesla}$$

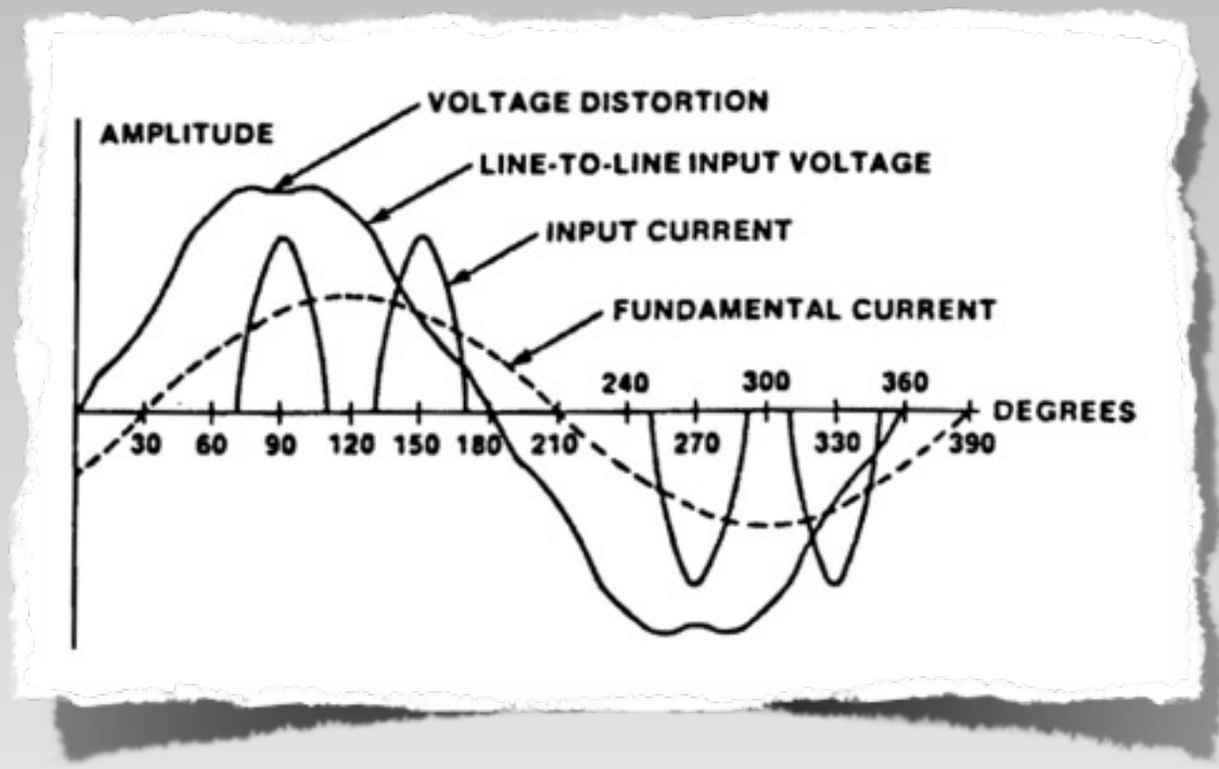
$$2 \times 10^{-17} = \frac{4 \times 10^{-3}}{r^3}$$

$$r \longrightarrow 40\,\mathrm{km} \quad \textit{without shielding!}$$

$$\delta \sim 1\,\mathrm{mm}$$

Power Line Effects





Source: D.A. Jarc and R.G. Schieman, "Power Line Considerations for Variable Frequency Drives," Proc. IEEE-IAS 1985 Annual Meeting

Transmission depends on isolation and line impedance

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