



IAEA Meeting on Achieving the Site End State: Characterisation  
Strategies and Instrumentation for Land Contamination (Thurso-Dounreay-Wick, 2019)



GOBIERNO  
DE ESPAÑA

MINISTERIO  
DE CIENCIA, INNOVACIÓN  
Y UNIVERSIDADES

Radiological Characterization of site Palomares:  
Historic evolution and current situation

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## **ACKNOWLEDGEMENTS**

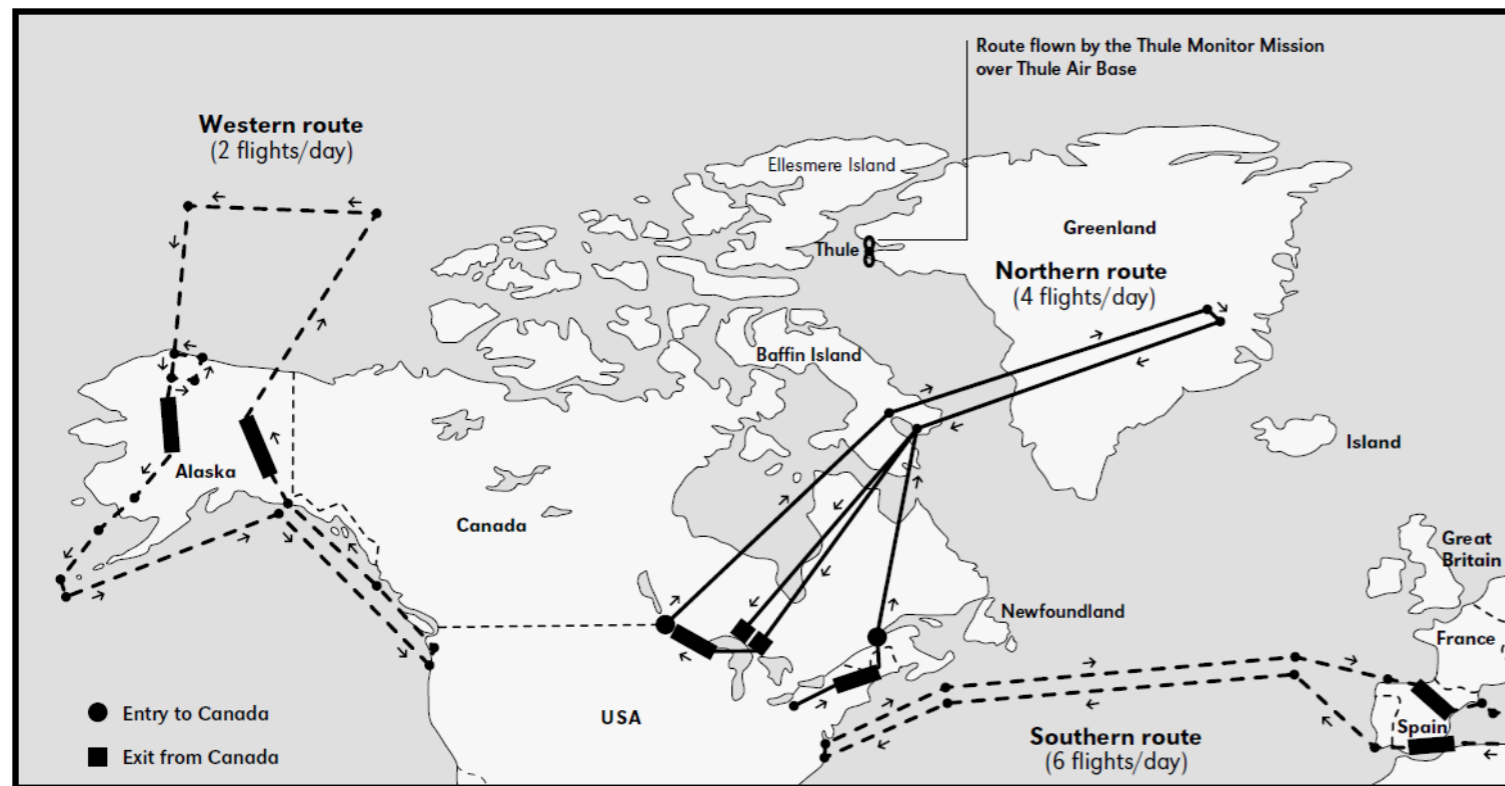
CIEMAT INDALO Project working since 1966 in the following of the impact of the Palomares accident in the population and environment

CIEMAT Environmental Restoration Project working since 2006 for the update of the radiological characterization of Palomares area and the restoration plans

The Palomares inhabitants and authorities, who always cooperated with CIEMAT in many ways

# Operation Chrome Dome (1961-1968)

## US Strategic Air Command



Refueling over Spain had been a standard daily procedure in the Chrome Dome flights since 1961, framed in military agreements signed by US and Spain in 1953.



# Palomares, 1966



**Almansora  
River**

**Sierra  
Almagrera  
(Saddle Rock)**

**Palomares**

**Villaricos**

**Jatico**

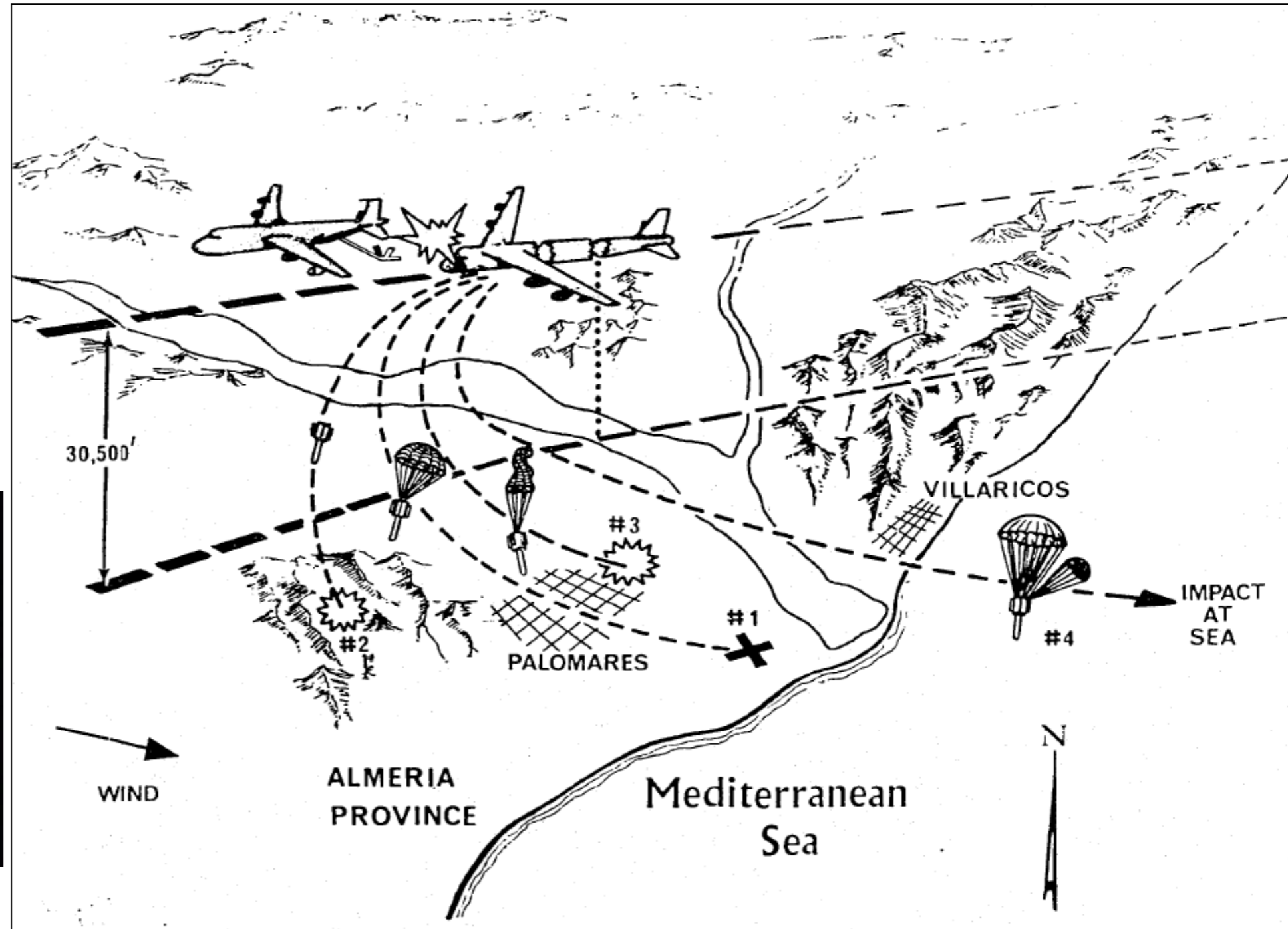
**Quitapellejos  
Beach**



## 17 January 1966, 09:22 GMT (10:22 local time in Palomares)

'Tea 16' B-52G bomber carrying four MK-28FI H-bombs (1.5 Mt TNT) and 'Troubador 14' KC-135A aerial tanker collided at 31000 ft (9.44 km) while engaged in the final stages of hookup for refueling.

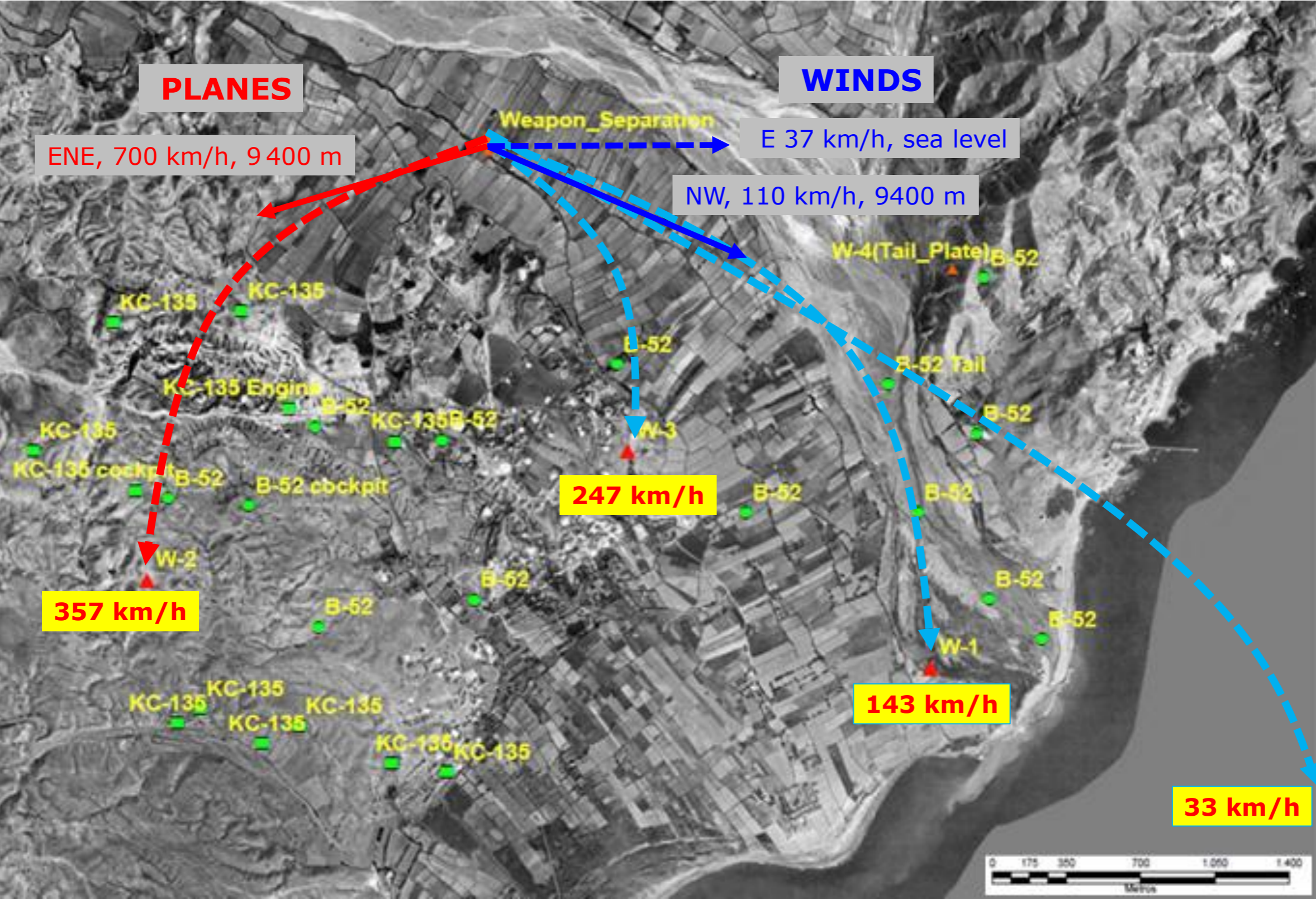
The four KC-135A crew members and three (of seven) B-52G tripulants were killed as a result of the accident.





# 17 January 1966, 09:22 GMT (10:22 local time in Palomares)

Debris pattern and contamination was spread over 15 km<sup>2</sup>



Adapted from Consejo de Seguridad Nuclear, 2013.



# 17 January 1966, 09:22 GMT (10:22 local time in Palomares)

No serious injuries to inhabitants, farm animals or buildings other than broken windows or similar ('The hand of God' said the local priest)





# The bombs of Palomares

Bombs 1 & 4 were found slightly damaged with the nuclear material undisturbed. Radiation checks were negatives.



**Bomb 1**  
**17/01/1966 afternoon**



**Bomb 4, 07/04/1966,**  
**Retrieved from 760 m deep**



*National Museum of Nuclear Science & History (Albuquerque, NM, EEUU)*

Bombs 3 & 4 were seriously damaged and high explosive detonated, affecting the nuclear material and significant alpha contamination was found in the area



**Bomb 2**  
**18/01/1966 08:30 GMT**

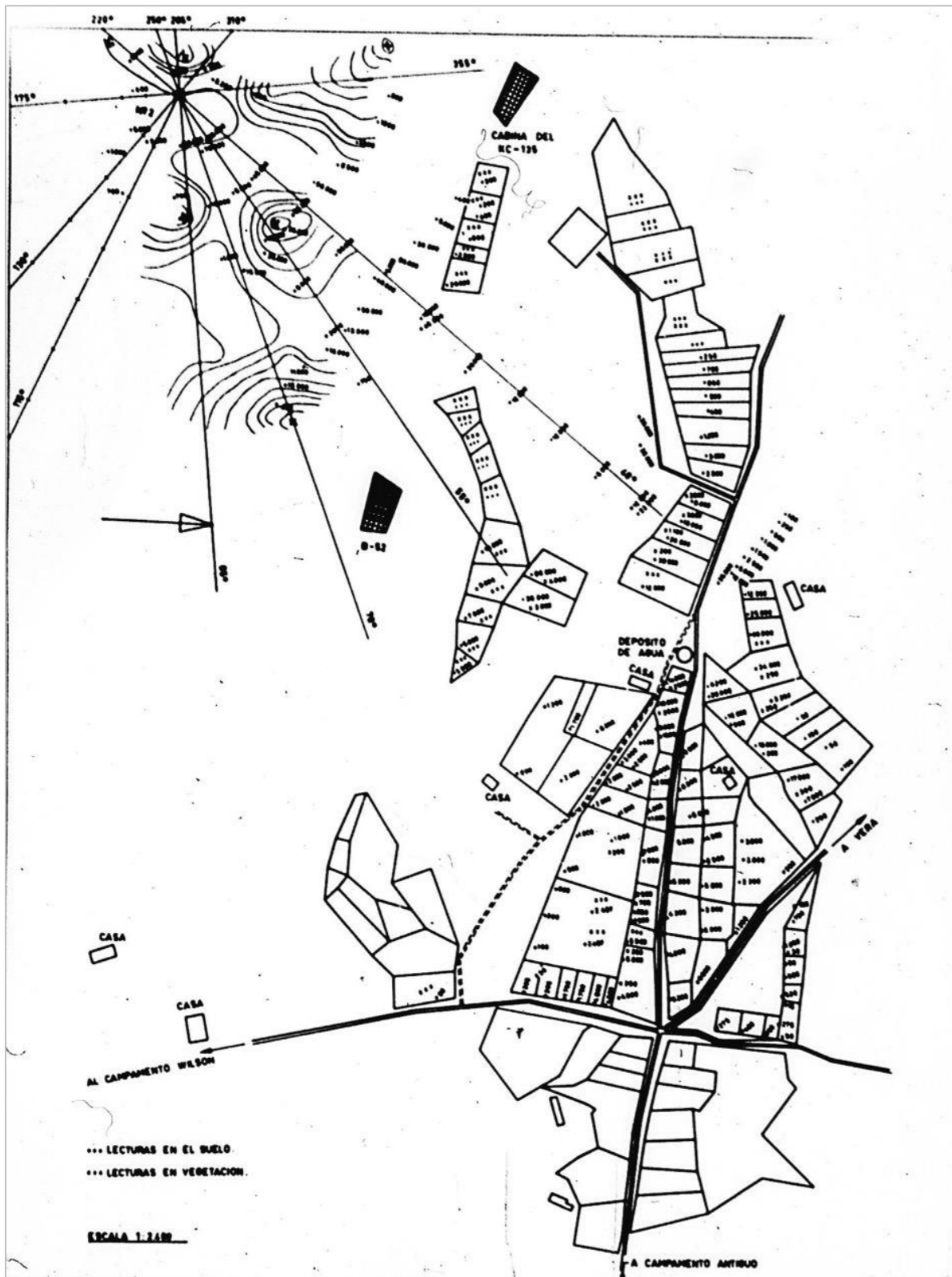


**Bomb 3**  
**18/01/1966 09:30 GMT**



**BROKEN ARROW:** Accidental event that involves nuclear weapons, warheads or components that does not create a risk of nuclear war.

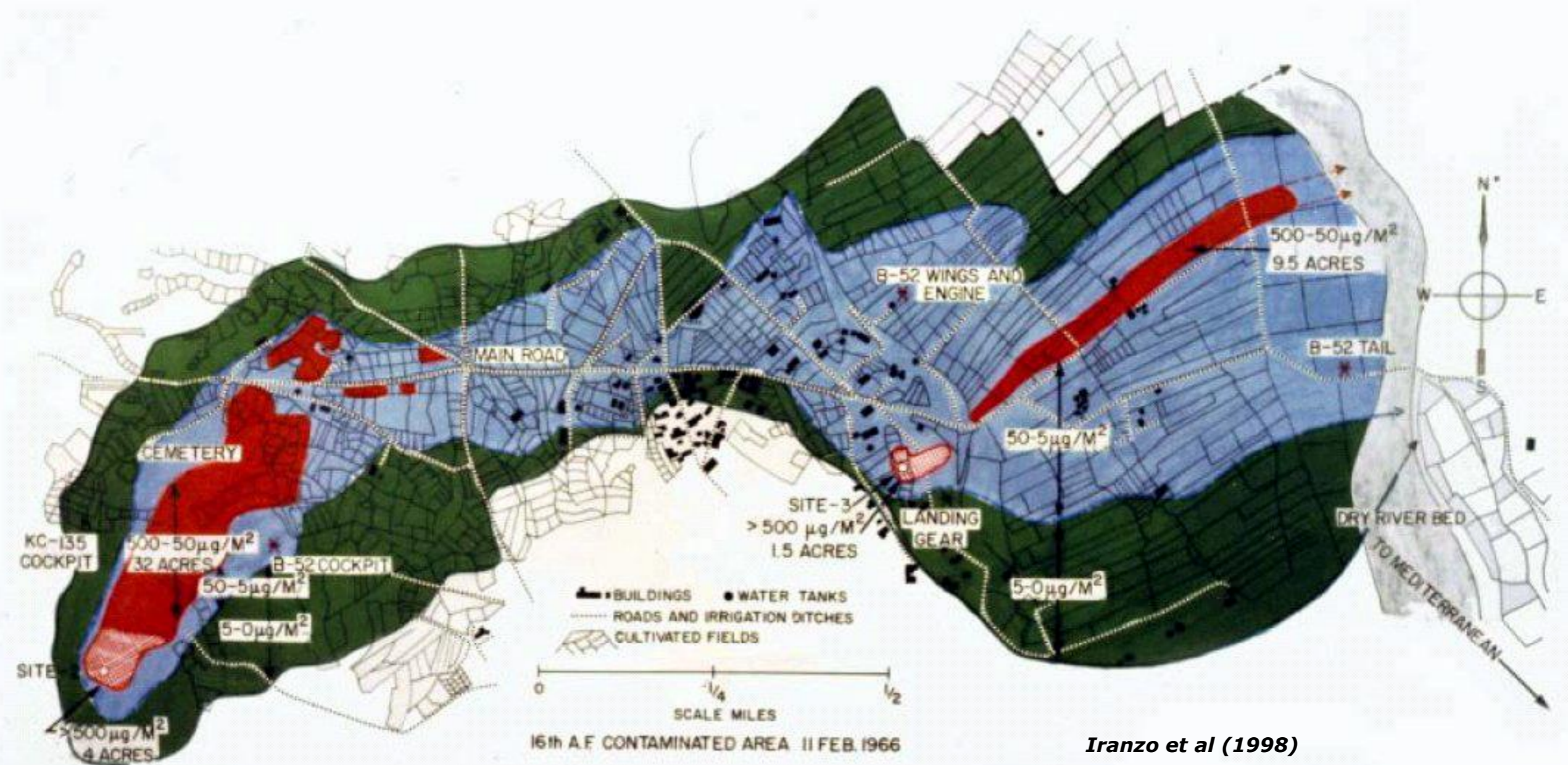
Immediate radioactive contamination surveys were conducted during six weeks by 200 military people using up to 20 Eberline PAC-1S  $\alpha$  scintillator (cpm).



Iranzo et al (1998)



'Zero Line' as stated by US-Air Force on 11 February 1966 in terms of  $^{239}\text{Pu}$  surface contamination units  $\mu\text{g}/\text{m}^2$  ( $130 \text{ cpm} \rightarrow 1 \mu\text{g}/\text{m}^2$ )



**About 6 kg  $^{239}\text{Pu}$  (13 TBq) were spread over 226 ha**

> 1200 kBq·m <sup>-2</sup> (2.2 ha, 12 TBq)
120 - 1200 kBq·m <sup>-2</sup> (17 ha, 0.9 TBq)
12 - 120 kBq·m <sup>-2</sup> (87 ha, 0.02 TBq)
< 12 kBq·m <sup>-2</sup> (120 ha, < 0.01 TBq)



# Lessons learned from the use of PAC-1S in Palomares (Place et al, 1975)

- 1) "Acceptable radiation levels had to be established according to the texture of the terrain
- 2) A more reliable field instrument should be developed to detect Pu-239
- 3) Due to the training and difficulties of alpha detection, experienced personnel is required
- 4) Extensive previous training is necessary to conduct a first-class monitoring
- 5) PAC-1S should only be deployed on the field under pertinent directives and repair capabilities

A new instrument was designed to detect the low energy but more penetrating X-rays and gammas present in weapon Pu."



***PAC-1S Alpha Scintillator detector***



***FIDLER: Field Instrument for Detection of Low Energy Radiation (photons)***



# US Remediation and Restoration actions

(22/01/1966 - 10/03 1966)

## USA – Spain Agreed remediation criteria (24/02/1966)

Material	Pu Surface activity	Actions	Results
<b>Soil: General access</b>	>1200 kBq/m <sup>2</sup> (> 120 Bq/g)*	Scraped and removed from Spain	832 m <sup>3</sup> from 2.2 ha (Zone 2)
	12-1200 kBq/m <sup>2</sup> (1.2 - 120 Bq/g)*	Watering and plowing down to 30 cm deep	115 ha
	< 12 kBq/m <sup>2</sup> (< 1.2 Bq/g)*	No actions	111 ha + 192 ha (Zone 6)
<b>Unexploited Soil and Hard Access</b>	< 180 kBq/m <sup>2</sup> (< 1.8 Bq/g)*	No actions	No data
<b>Vegetables and crops</b>	> 7 kBq/m <sup>2</sup> (> 10.7 Bq/g)*	Scraped and removed from Spain	306 m <sup>3</sup> from 115 ha
	< 7 kBq/m <sup>2</sup> (< 0.7 Bq/g)*	Burned and buried in the site	9250 t

\* Fresh contamination resided in the surface or first cm of soil and therefore 1 kBq/m<sup>2</sup> means about 0.1 Bq/g 12



# US Remediation and Restoration actions (22/01/1966 - 10/03 1966)

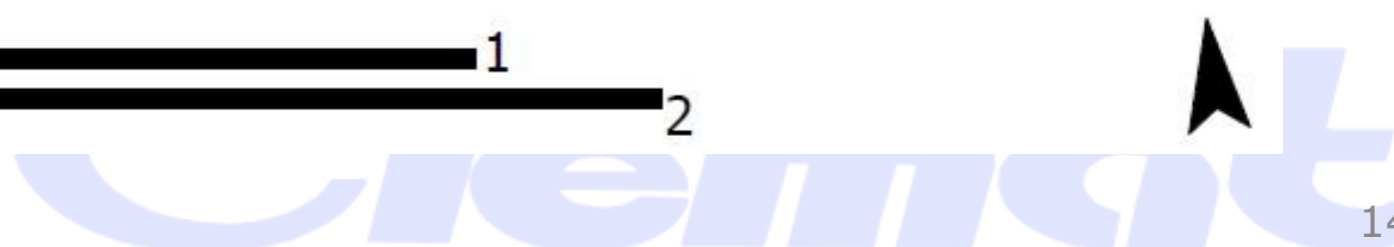




# Palomares, 2019



Google earth





## Radiological criteria for Palomares area (2004)

The Spanish Nuclear Safety Council (Consejo de Seguridad Nuclear, "CSN") established in 2004 the following criteria for the protection of the population in Palomares region:

- i) To **totally restrict** activities that could lead to a residual dose level equal to or greater than 5 mSv/y. The derived soil concentration for 5 mSv/y is 25 Bq/g  $^{239}\text{Pu}$ , and
- ii) To **partially restrict** areas and carry out additional studies when activities may give rise to a residual dose of between 1 and 5 mSv/y. The derived soil concentration for 1 mSv/y is 5 Bq/g  $^{239}\text{Pu}$ .

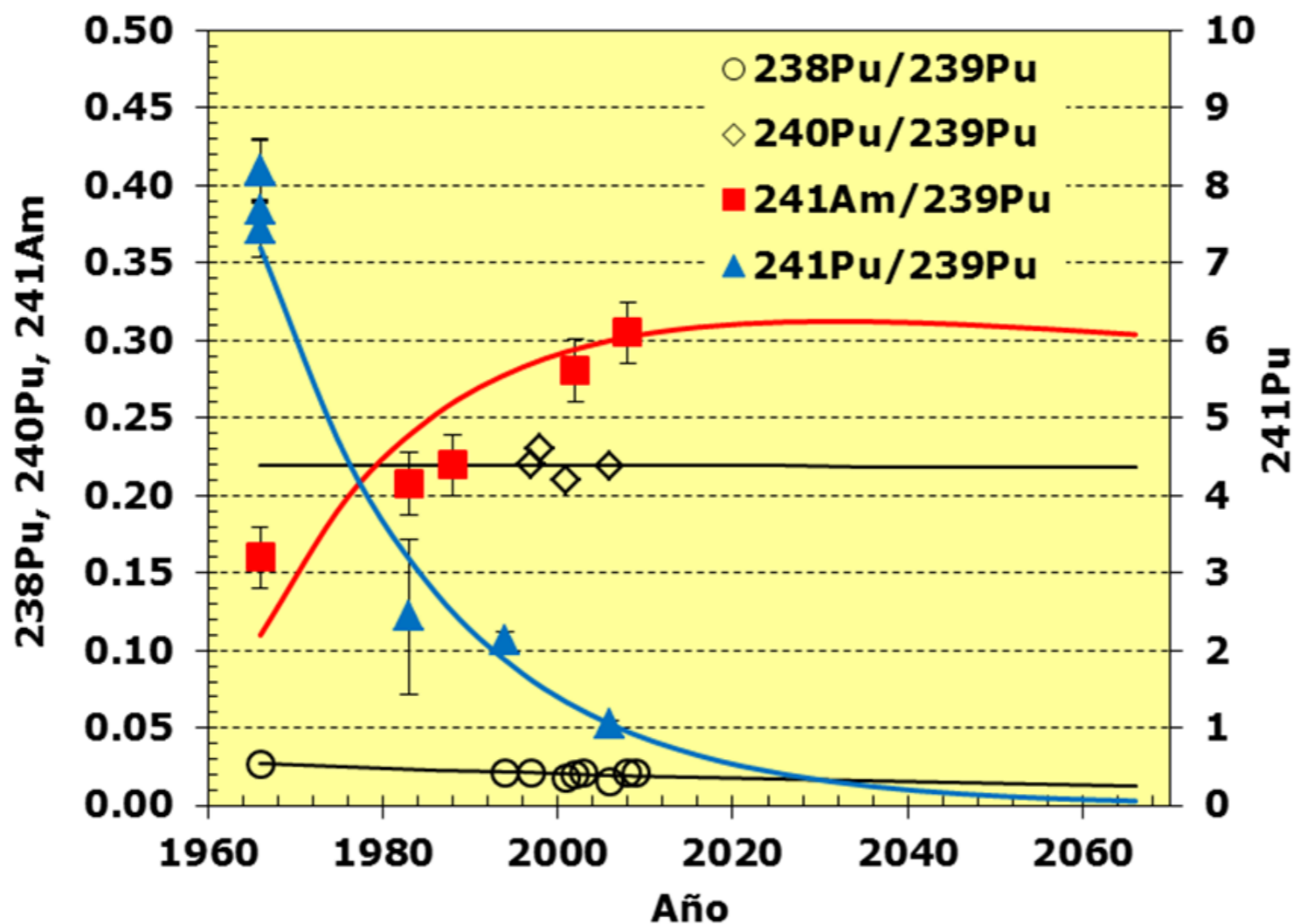
In 2015, Spain and USA agreed a relaxed criterium for Zone 6 (Sierra Almagrera) considering the expected protection area with no human activities

Homogeneous soils in the first 30 cm affected by natural processes and agriculture exploitation (Attwood, 1998).

Effective dose Budget: Inhalation due to Resuspension (70%), Local food ingestion (25%), External irradiation (3%) and other ingestions (2%).



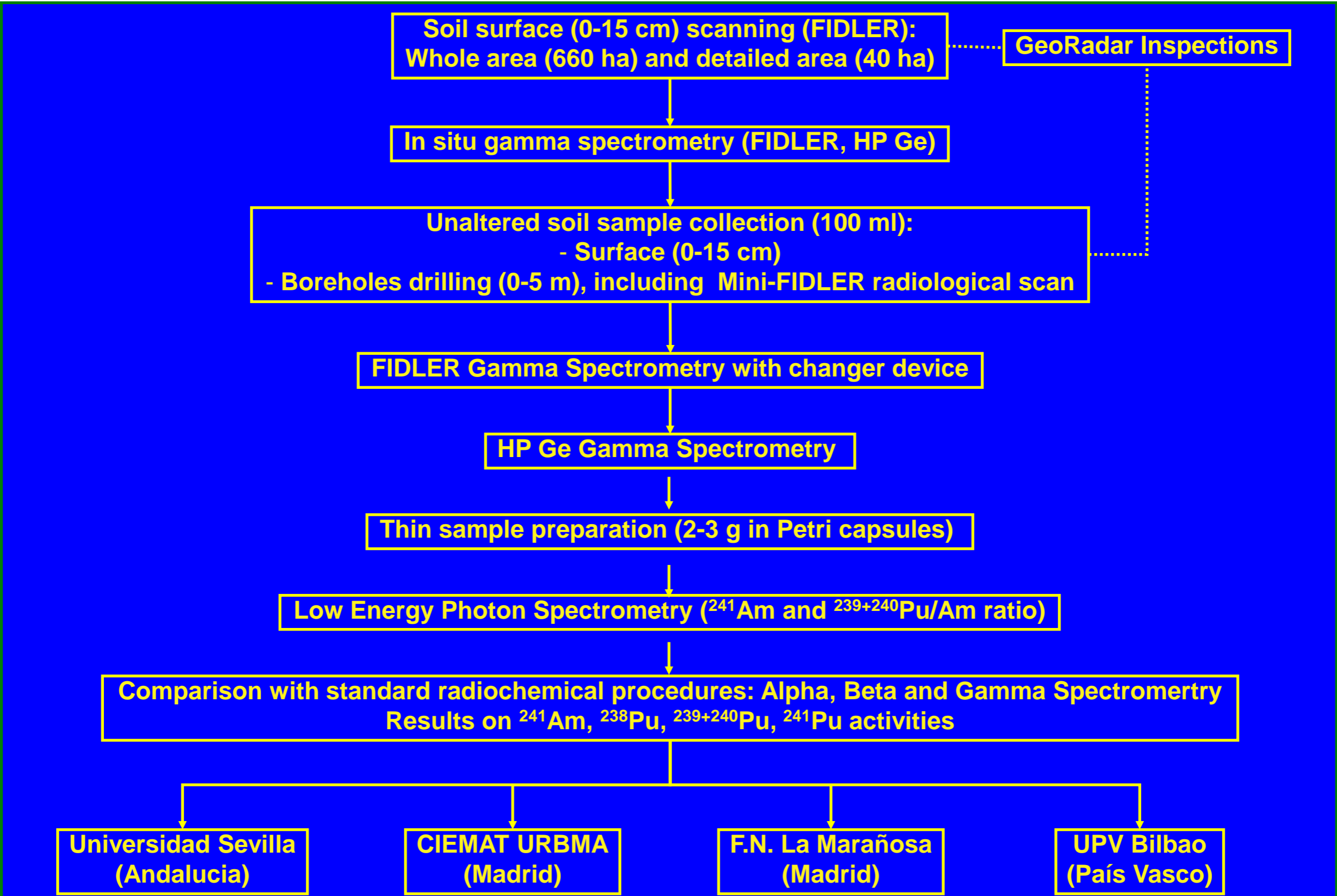
# Radiological criteria for Palomares area (2004)



Soil use criteria	Effective Dose mSv/a	[ <sup>239+240</sup> Pu] Bq/g	[ <sup>241</sup> Am] <sub>eq</sub> Bq/g
Total restriction	> 5	>25	> 5
Partial restriction	1 – 5	5 – 25	1 – 5



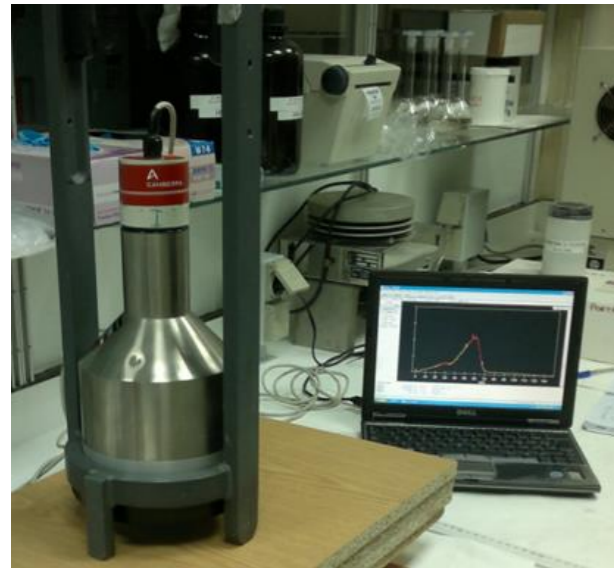
# Palomares 3D Radiological Characterization (2008-2010)



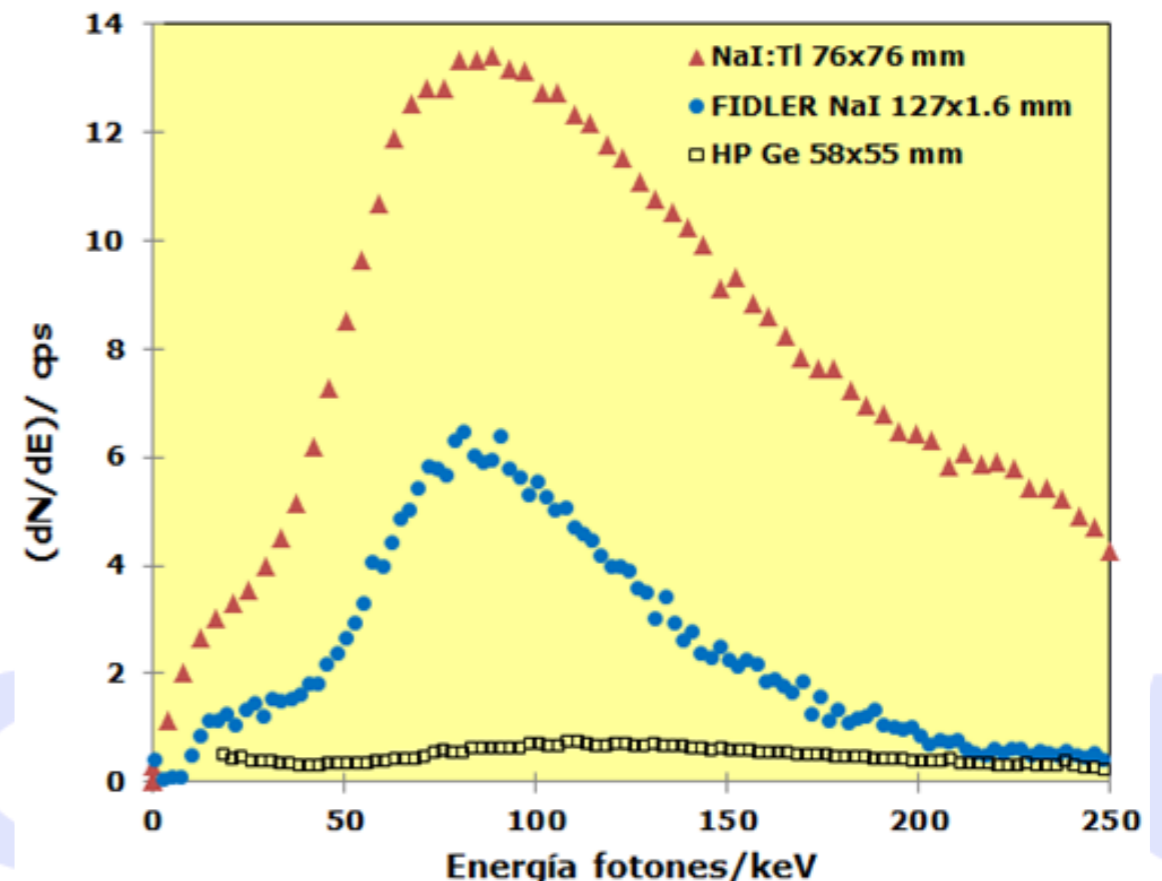
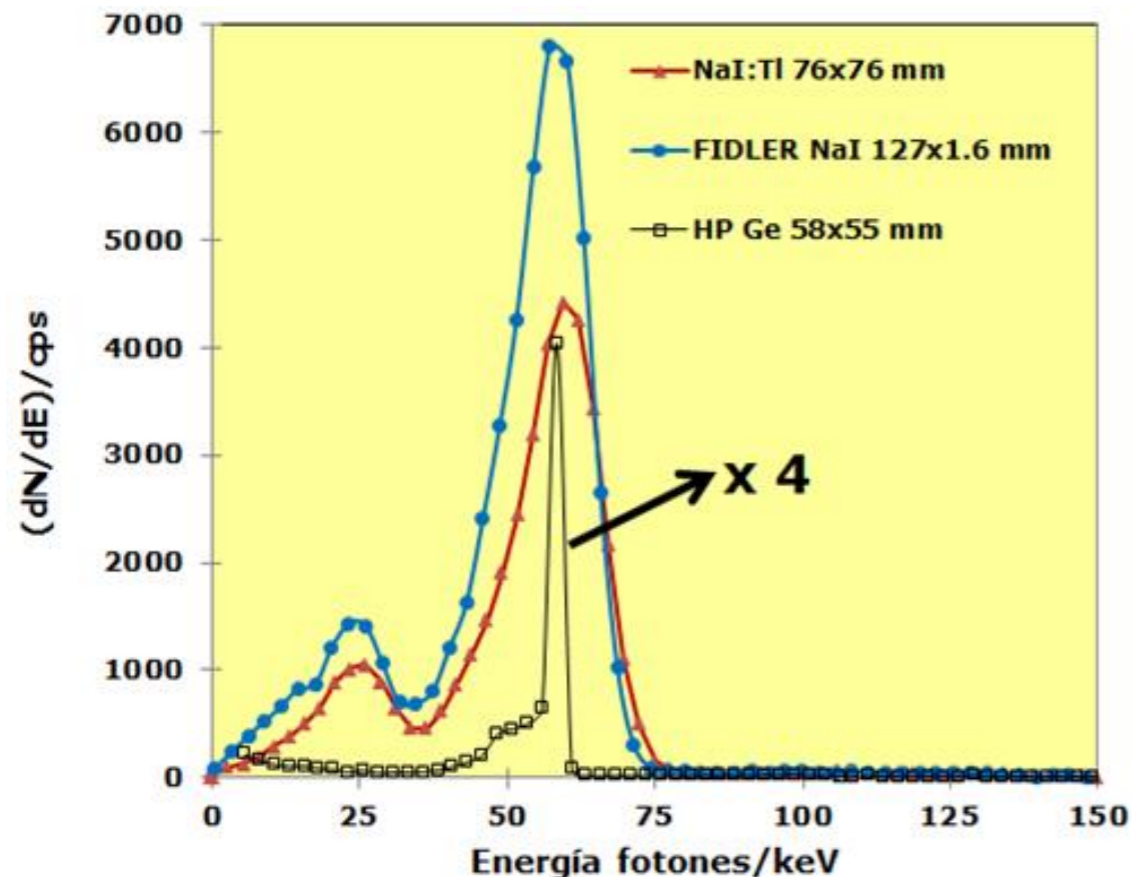


# FIDLER, Field Instrument for the Detection of Low Energy Radiation

- Developed by USAF after the Palomares accident
- NaI:TI 12.7 cm diameter ( $S=117 \text{ cm}^2$ ) and 0.16 cm thickness
- Mini-FIDLER: NaI:TI 2.5 cm diameter ( $S=5 \text{ cm}^2$ ) and 0.25 cm thickness



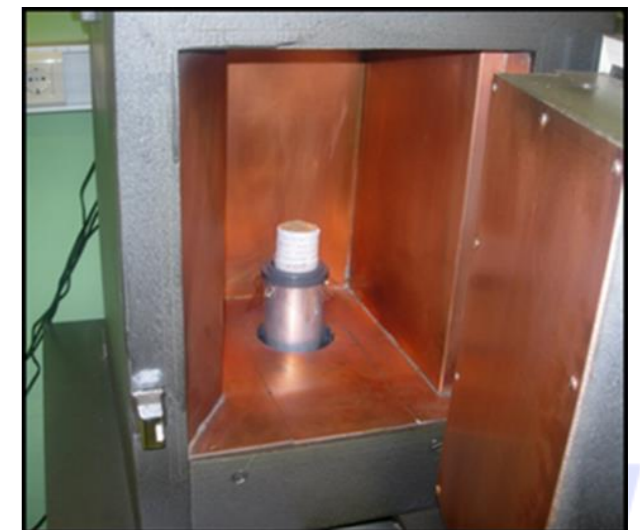
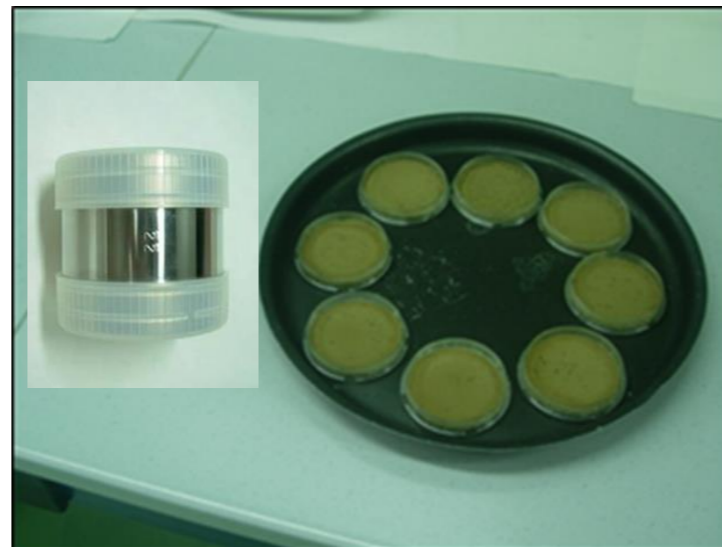
Detector	Efficiency 60 keV (point source)	Background 60 keV cps	MDA, Bq		
			t=2 s	t=300 s	t=3 600 s
NaI:TI 3x3	7.16E-02	1.05E+02	509	39	11
FIDLER	1.04E-01	4.90E+01	248	18	5
HP-Ge	5.39E-03	2.53E+00	1472	83	23





# Radiological Characterization: Top soil (0 – 15 cm)

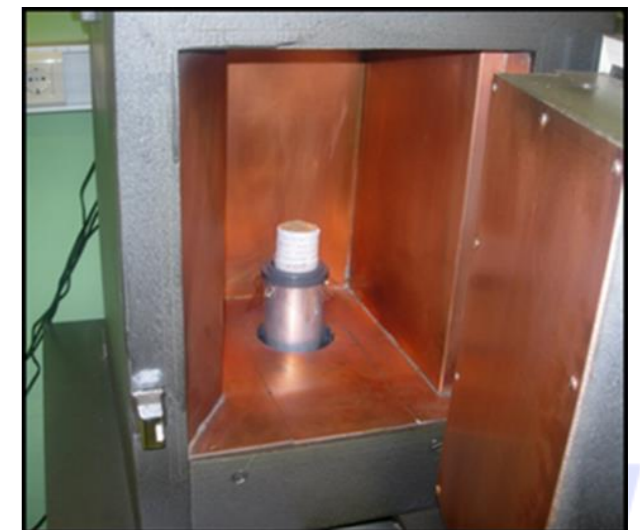
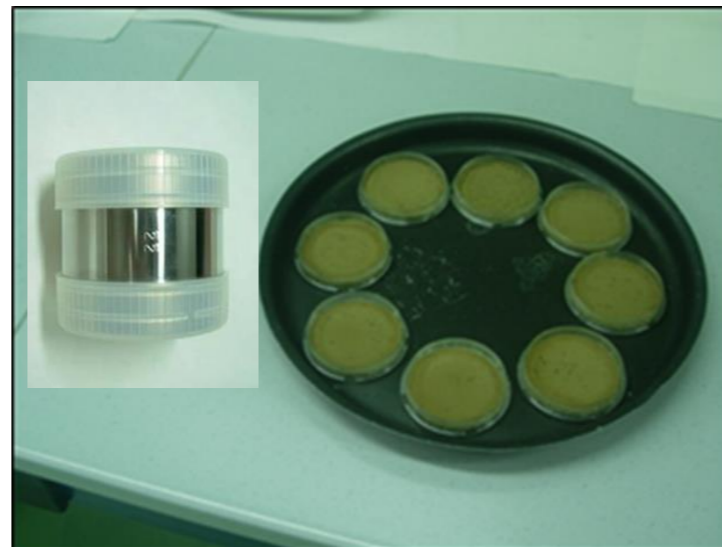
Measurement	Instrument (Acquisition time)
Dynamic In Situ Gamma Spectrometry	FIDLER (2 – 5 s)
Static In Situ Gamma Spectrometry	FIDLER, HP Ge (5 – 30 min)
Dose rate	Plastic scintillator Atomtex (1 min)
Unaltered soil samples	FIDLER x 2, HP Ge (1 – 10 min)
Granulometry	HP Ge (1 -10 min)





# Radiological Characterization: Top soil (0 – 15 cm)

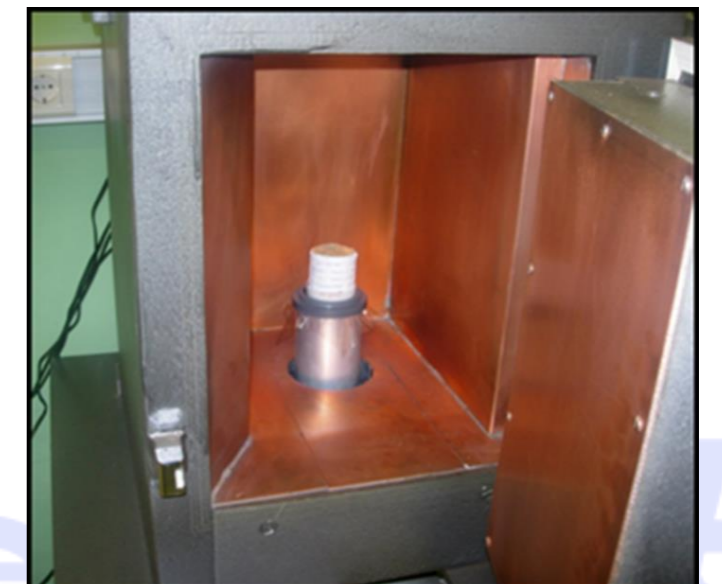
Measurement	Instrument (Acquisition time)
Dynamic In Situ Gamma Spectrometry	FIDLER (2 – 5 s)
Static In Situ Gamma Spectrometry	FIDLER, HP Ge (5 – 30 min)
Dose rate	Centelleo plástico Atomtex (1 min)
Unaltered soil samples	FIDLER x 2, HP Ge (1 – 10 min)
Granulometry	HP Ge (1 -10 min)





# Radiological Characterization: Subsoil (0 – 5 m)

Measurement	Instrument (Acquisition time)
Radiological profile of borehole samples	Mini-FIDLER (2 s)
Unaltered soil samples	FIDLER x 2, HP Ge (5 - 10 min)





# Radiological Characterization: Particle size studies (Granulometry)

## Measurement

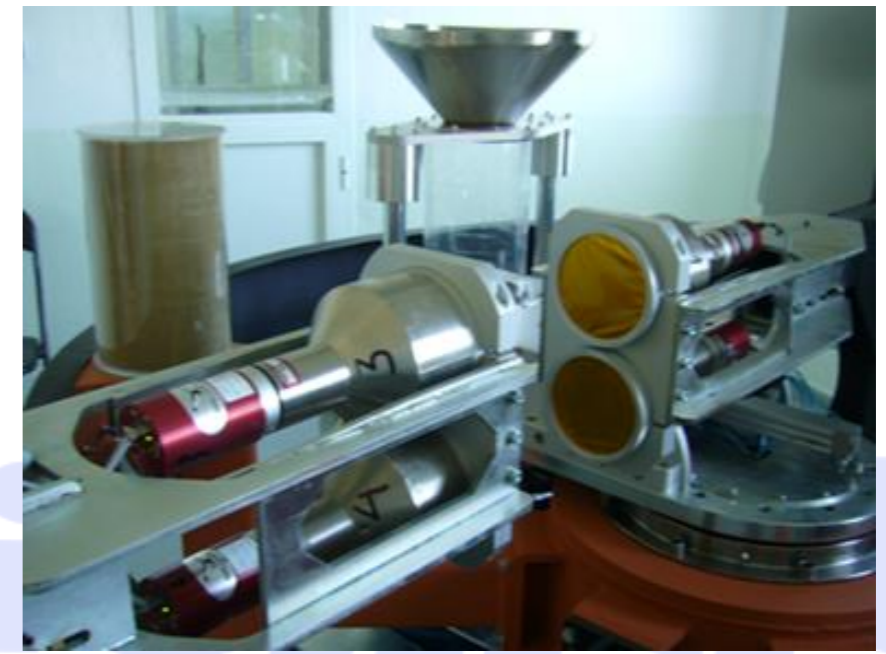
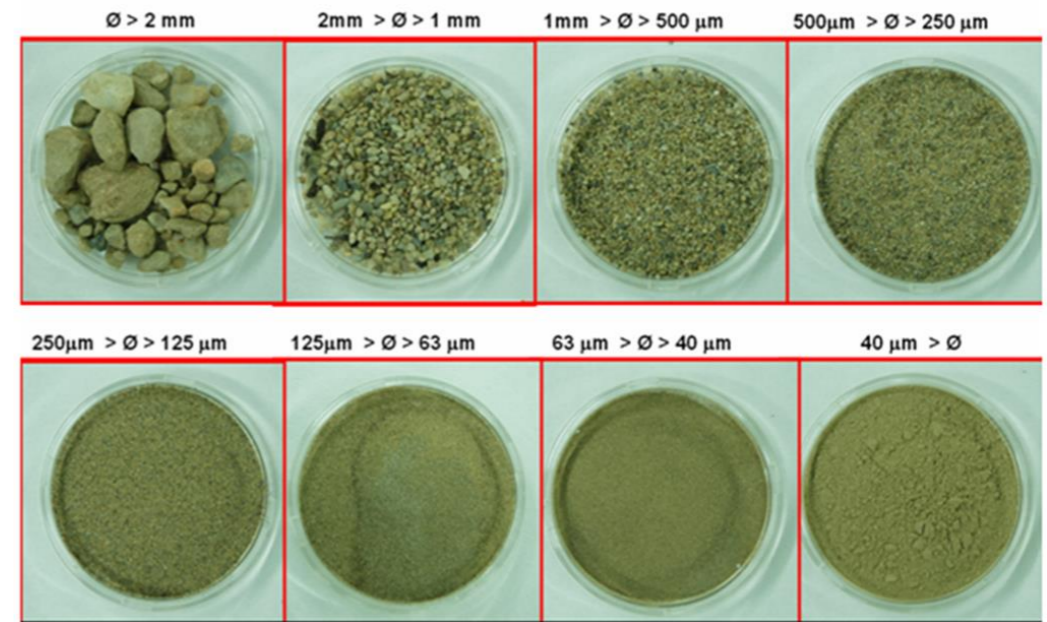
## Instrument (Acquisition time)

Laboratory (0.1 dm<sup>3</sup>)

Dry cyclon separator, HP Ge (5 min)

Pilot Plant (10 dm<sup>3</sup>)

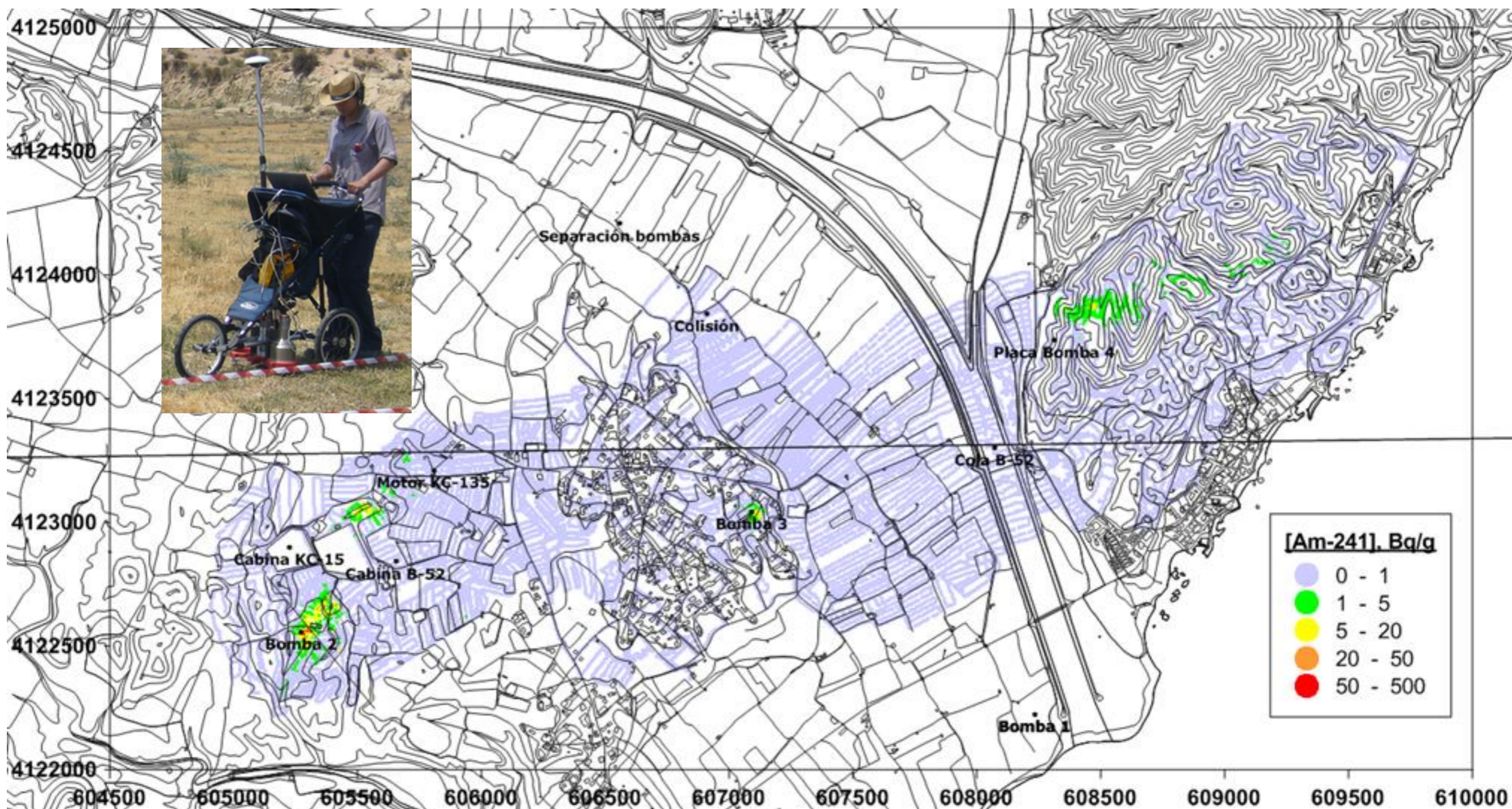
Prototype, FIDLER x 4 (1 – 5 min)





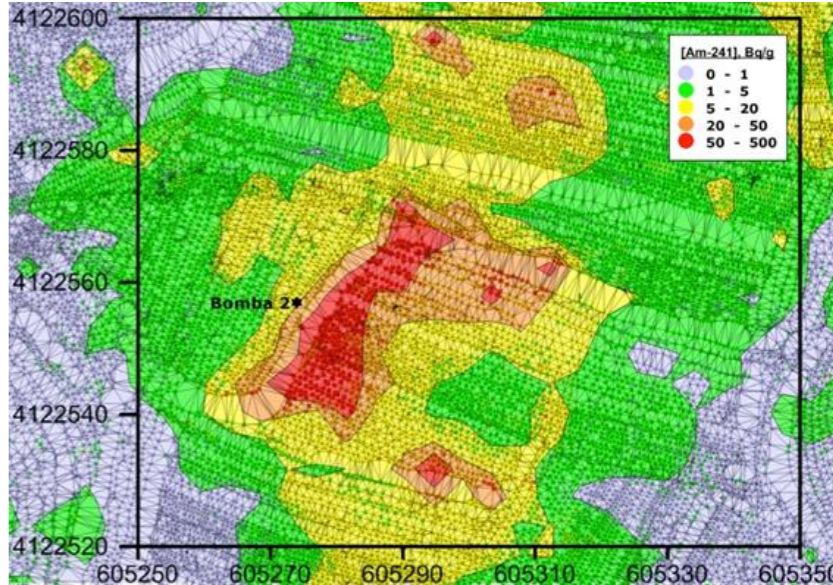
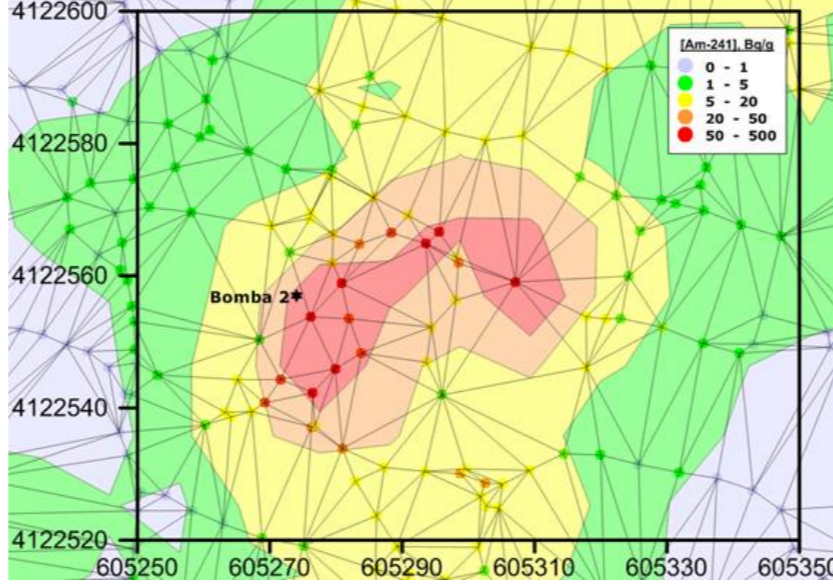
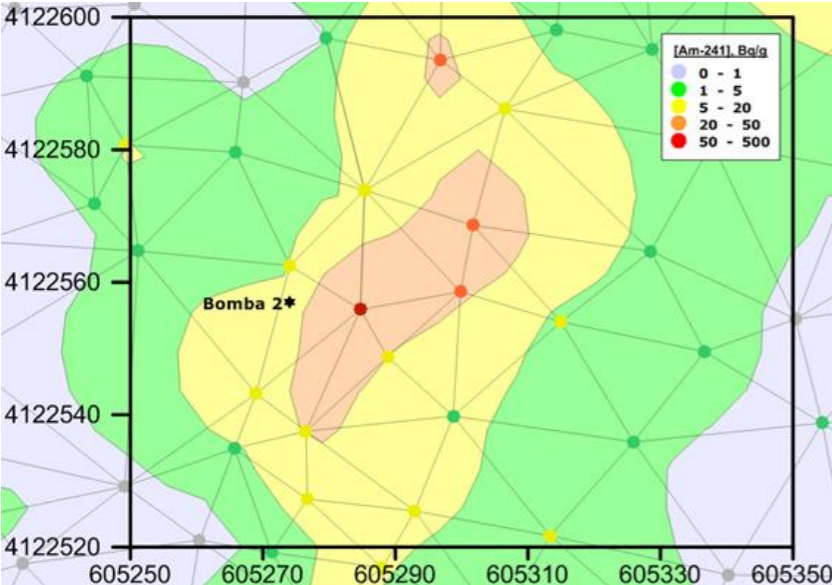
# Topsoil radiological extensive characterization:

430 km walked on 25 x 25 m<sup>2</sup> (63 000 data)





# Geostatistics approach: poligonal interpolation, natutral neighbor

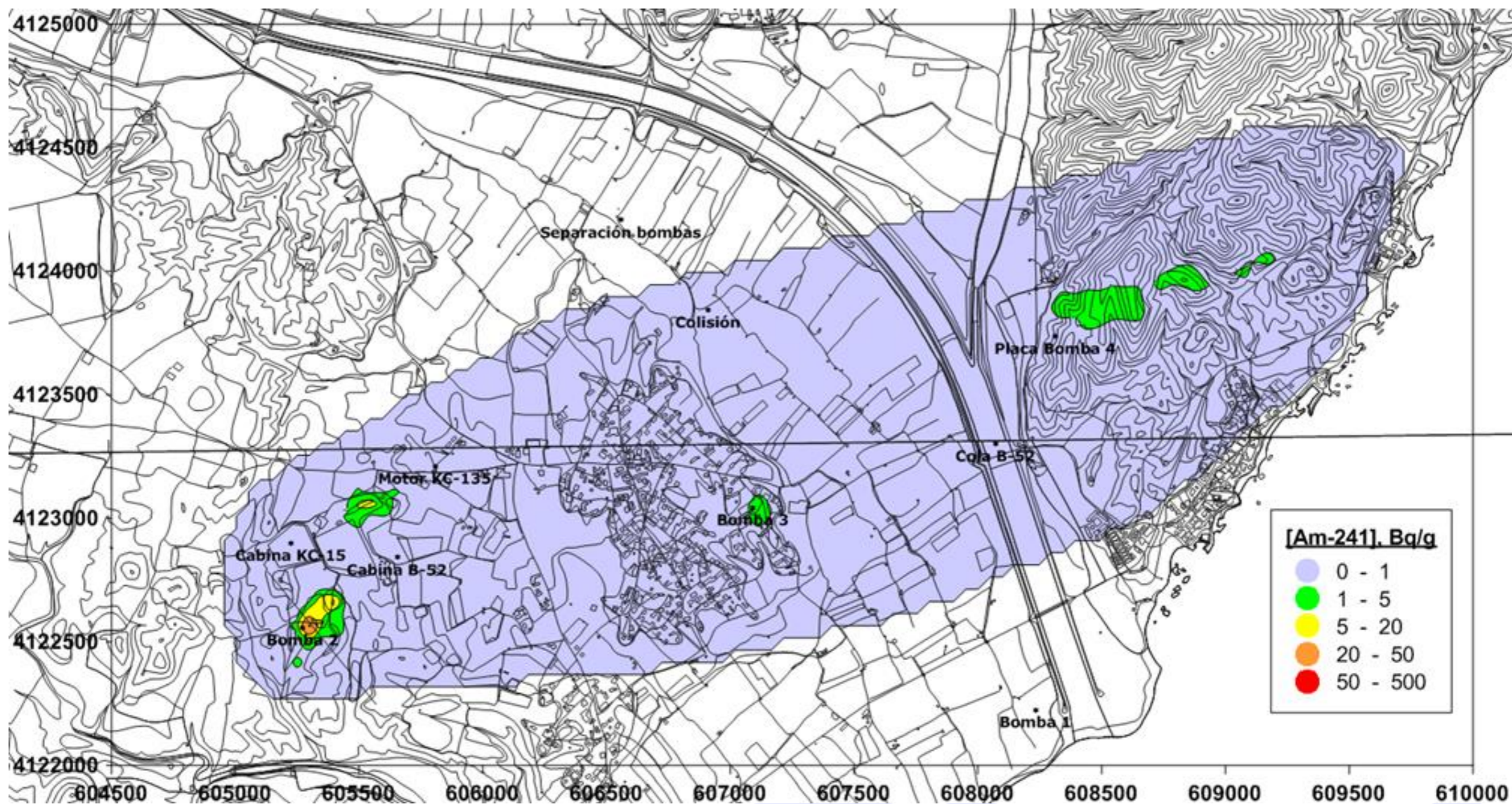


Dynamics Extensive	Statics	Dynamics Intensive
30 points	100 points	8 000 points
14 x 14 m <sup>2</sup>	5 x 5 m <sup>2</sup>	0.4 x 0.4 m <sup>2</sup>
105 m <sup>2</sup> /measurement	20 m <sup>2</sup> /measurement	0.5 m <sup>2</sup> /measurement



# Top-soil radiological extensive characterization:

430 km walked on a net 25 x 25 m<sup>2</sup> (63 000 data)



**601 ha**

**14.7 ha**  
**22 050 m<sup>3</sup>**

**2.5 ha**  
**3 750 m<sup>3</sup>**

**0.8 ha**  
**1 200 m<sup>3</sup>**

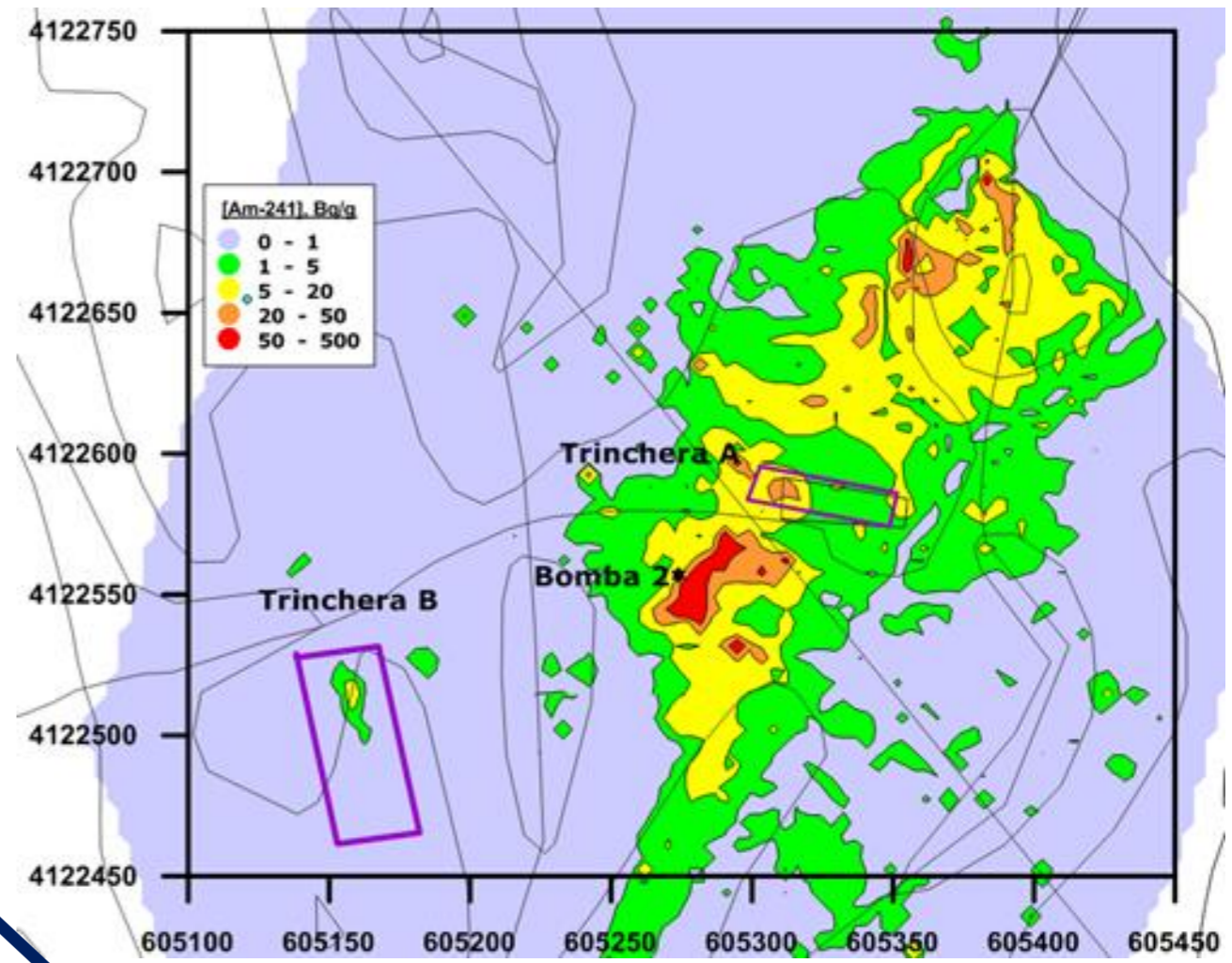
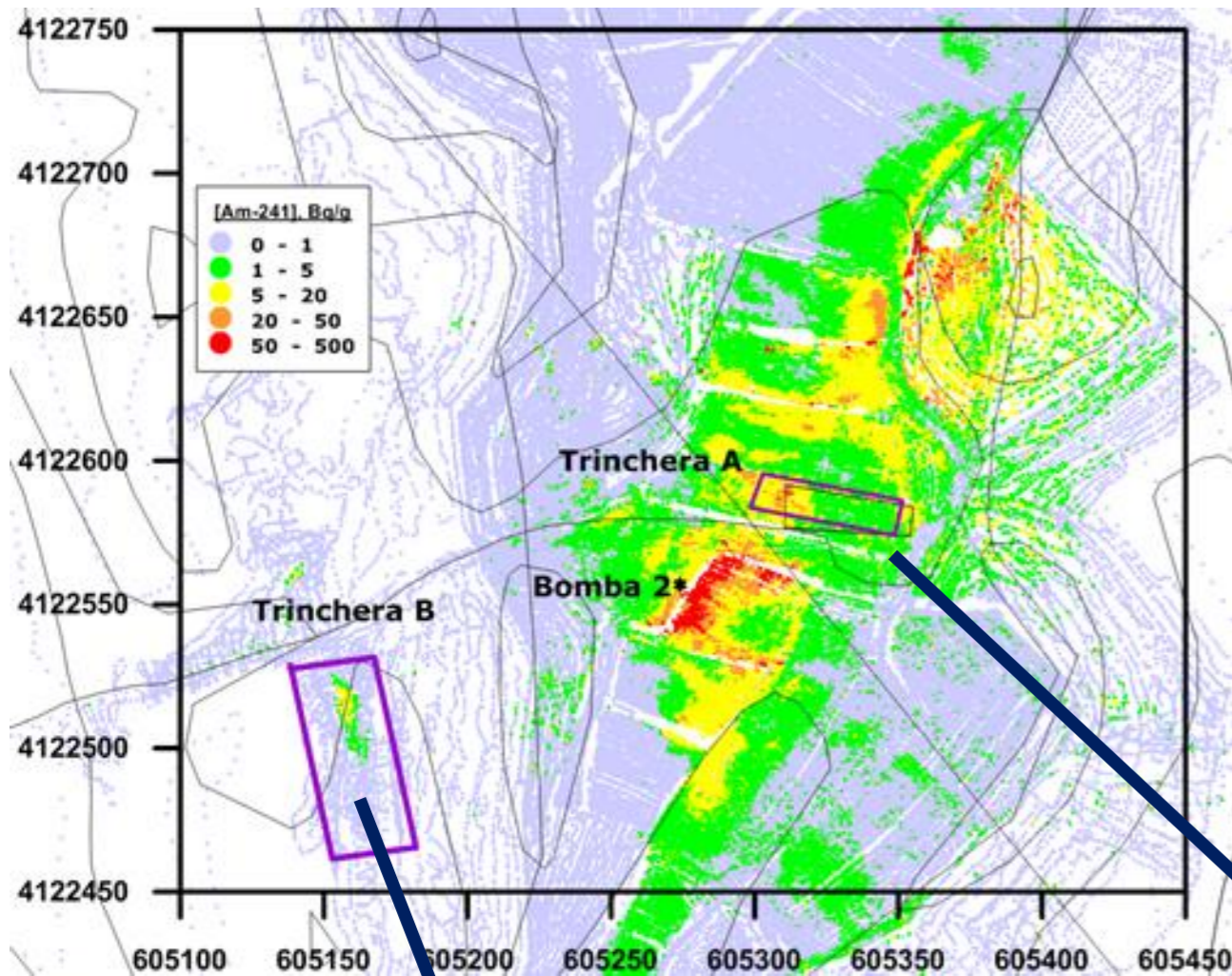
**0.4 ha**  
**600 m<sup>3</sup>**



# Top-soil radiological intensive characterization (Zone 2):

200 km over a net 1 x 1 m<sup>2</sup> (203 000 data)

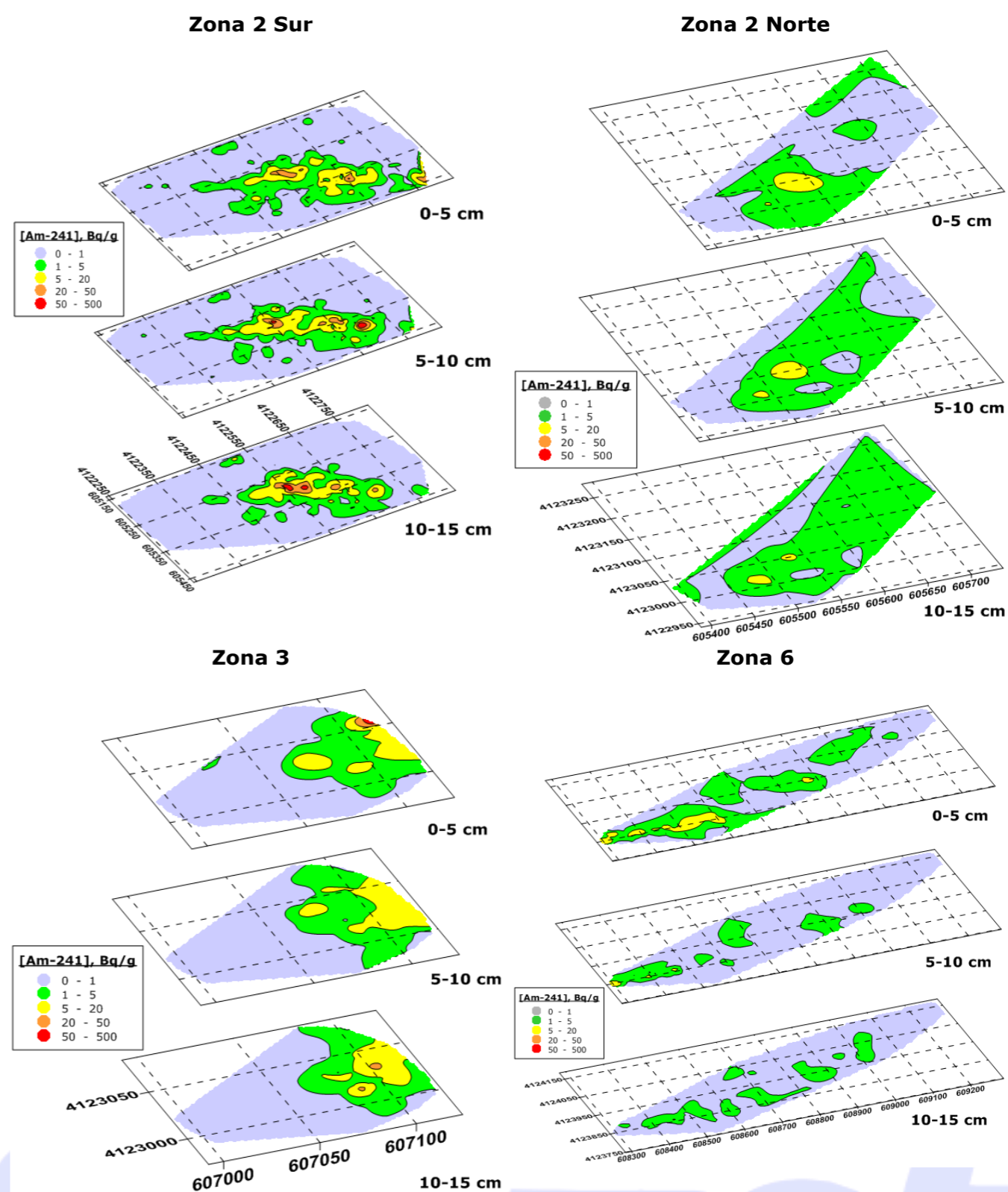
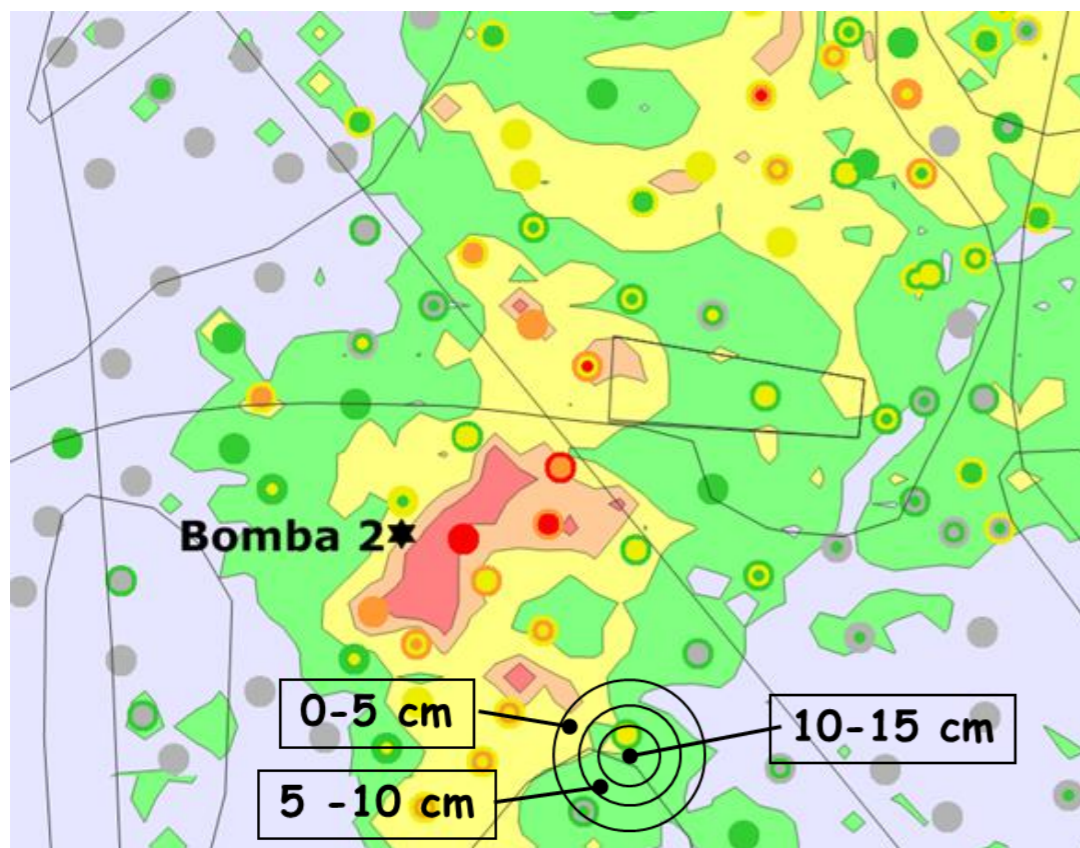
Location of burial pits





# Activity distribution in the top-soil (0 – 15 cm):

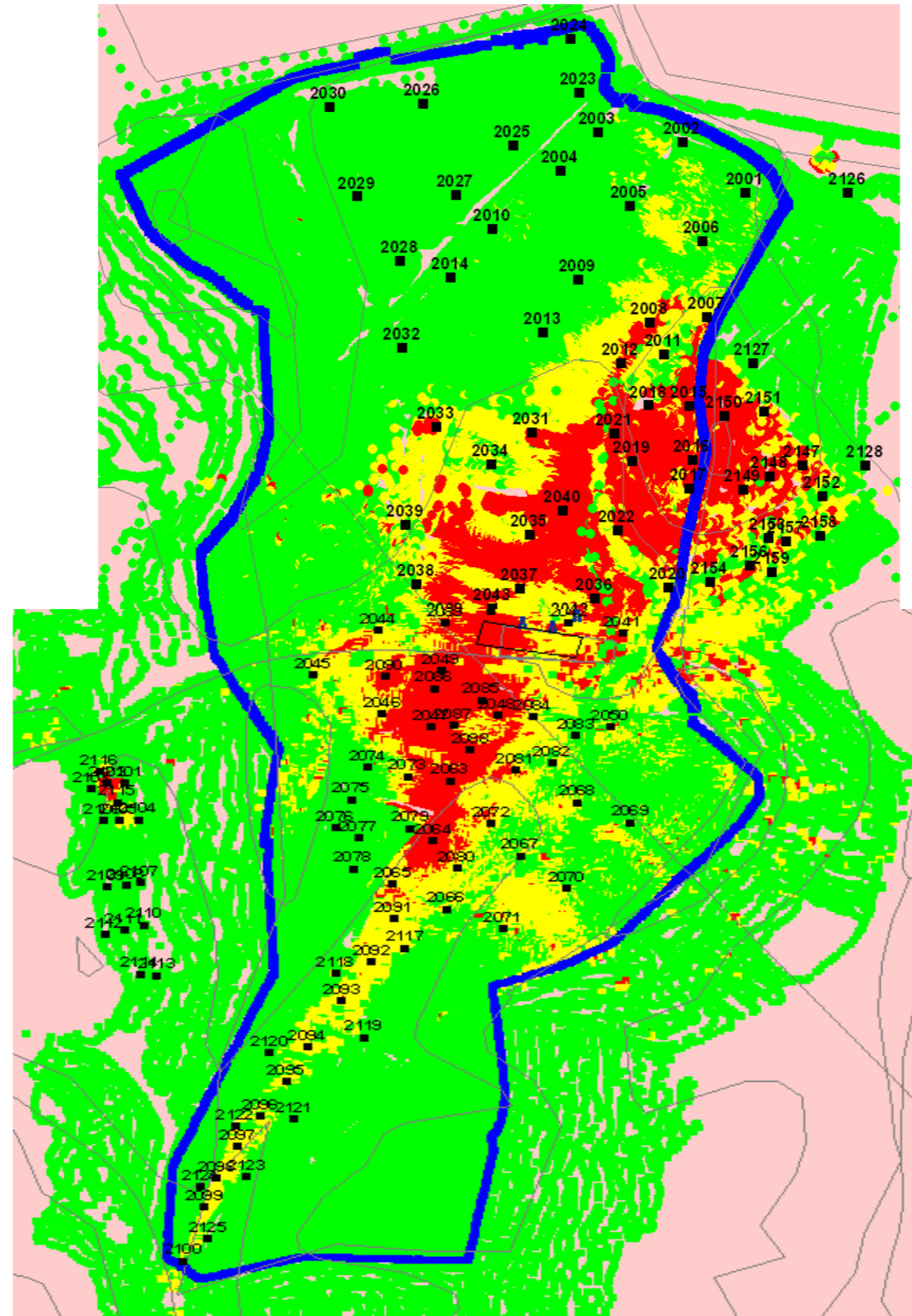
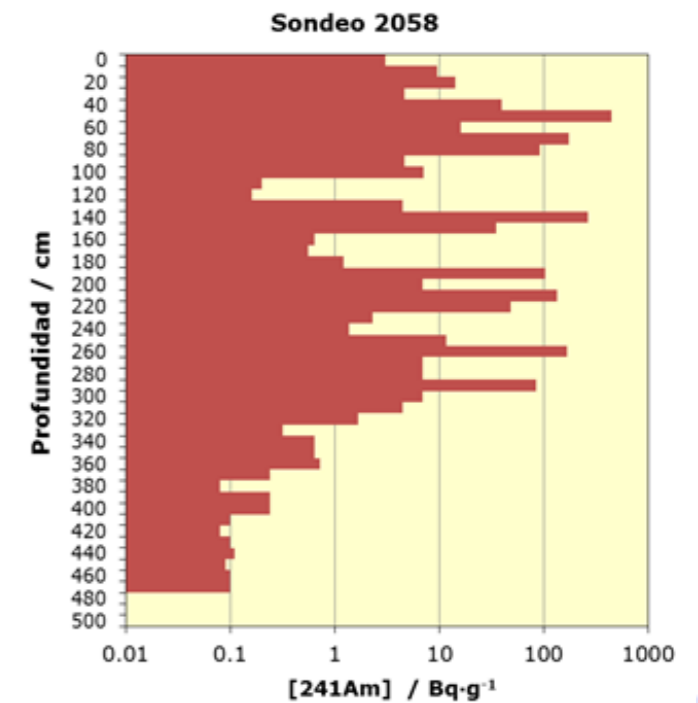
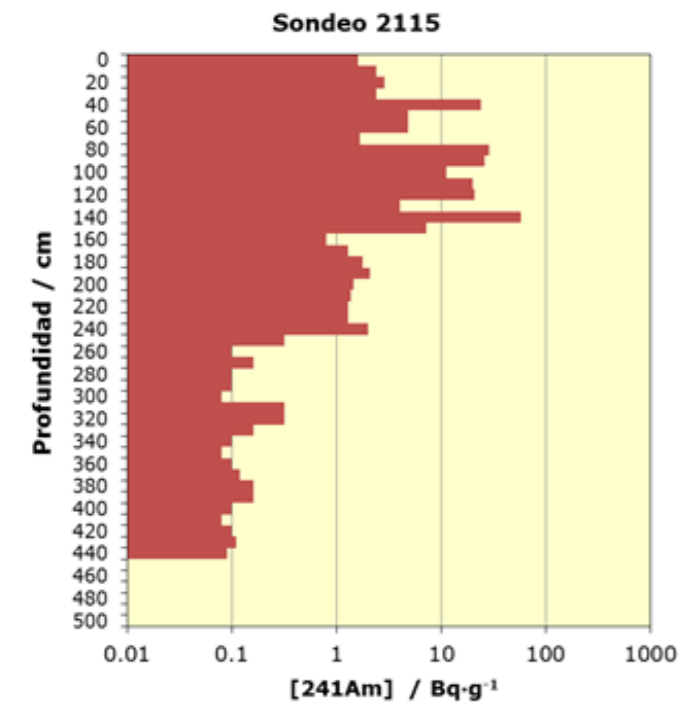
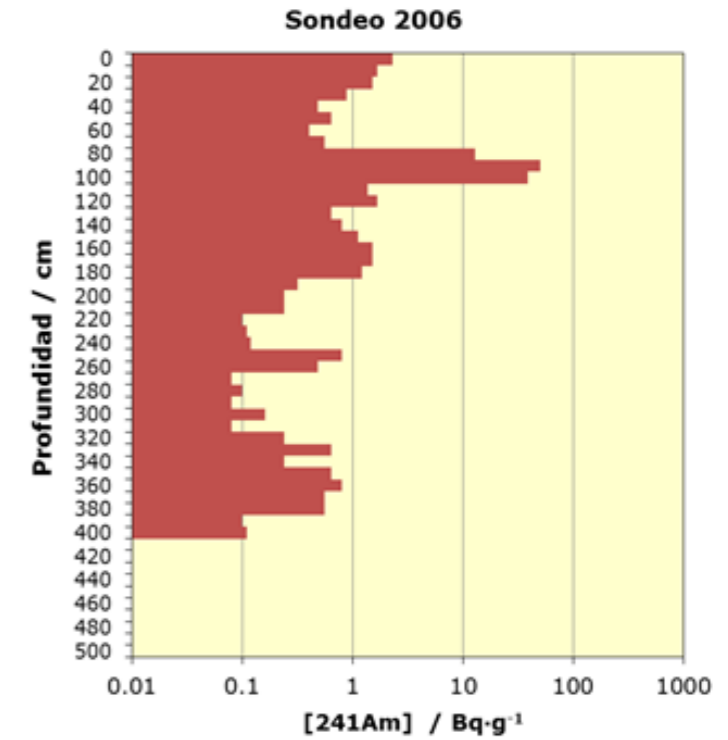
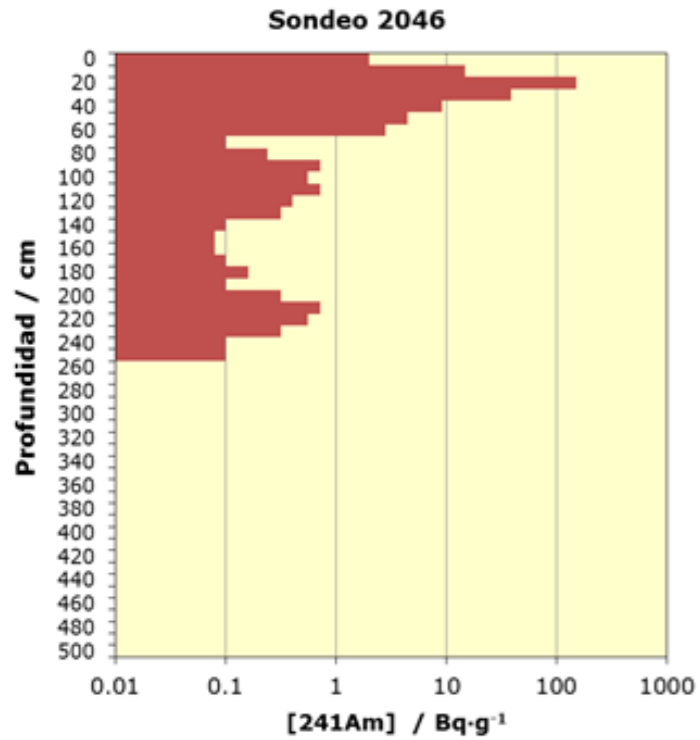
1 854 unaltered samples from 618 points





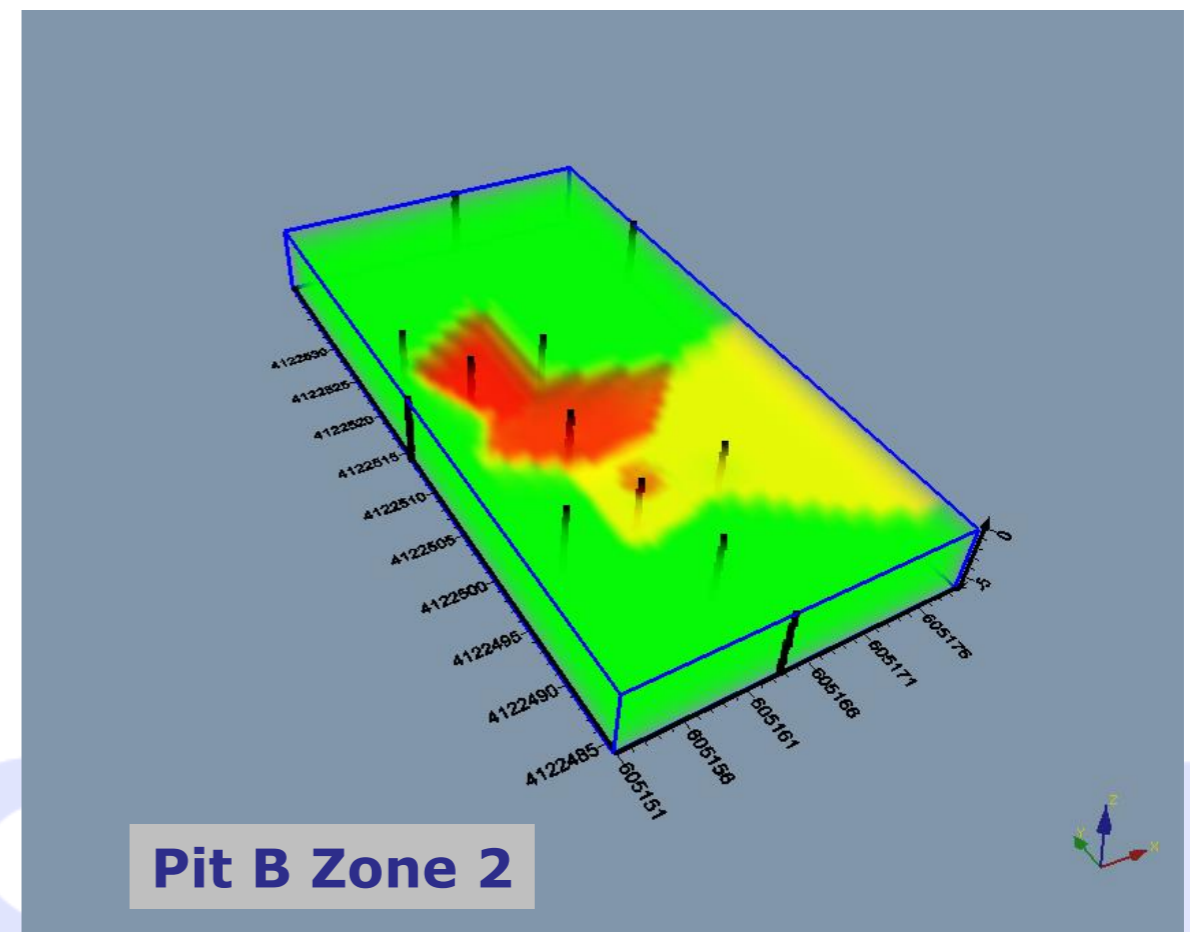
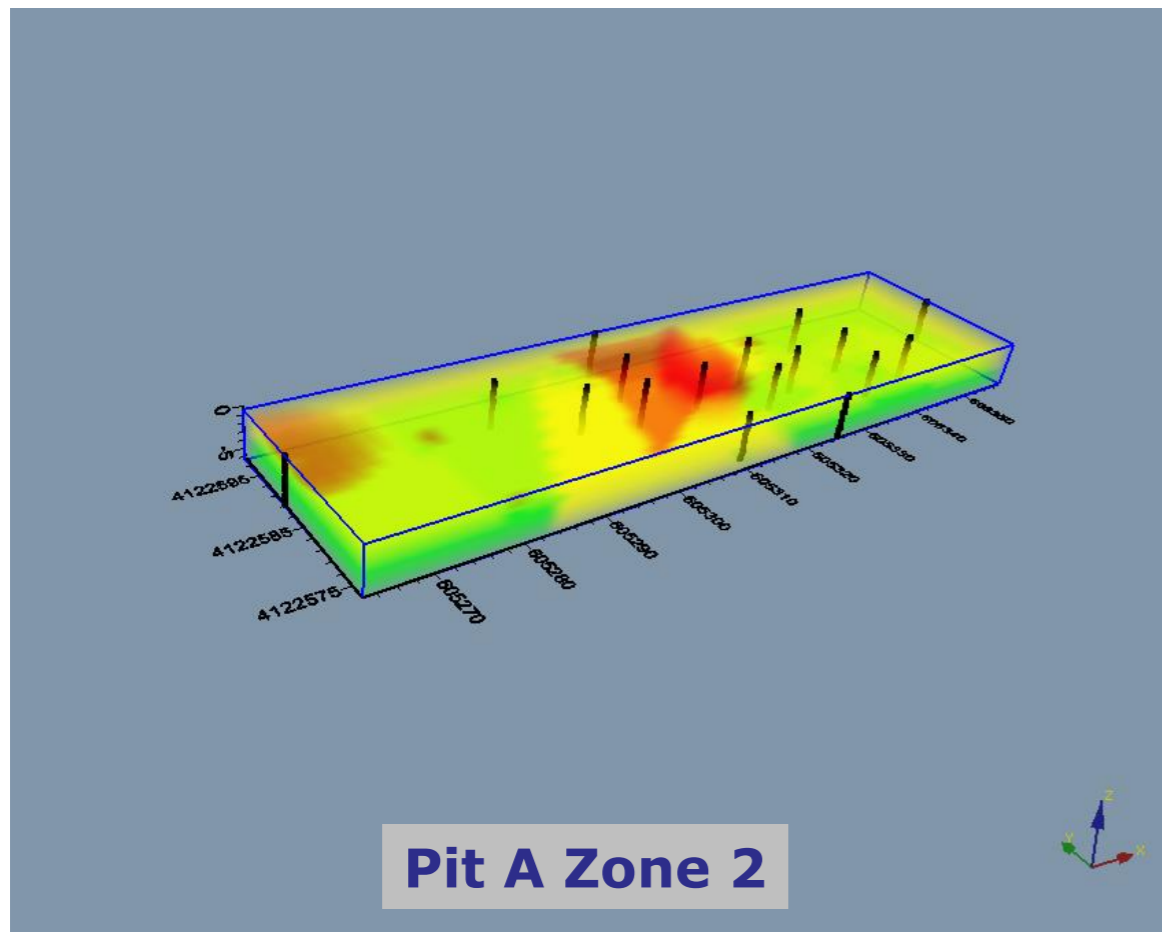
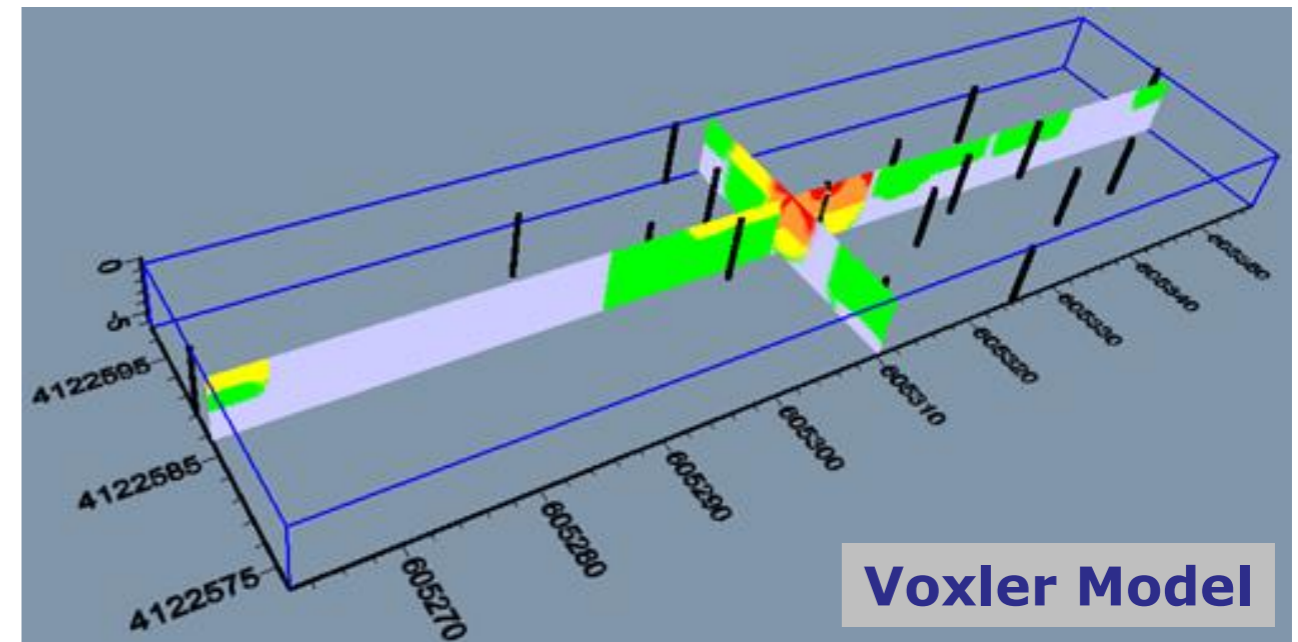
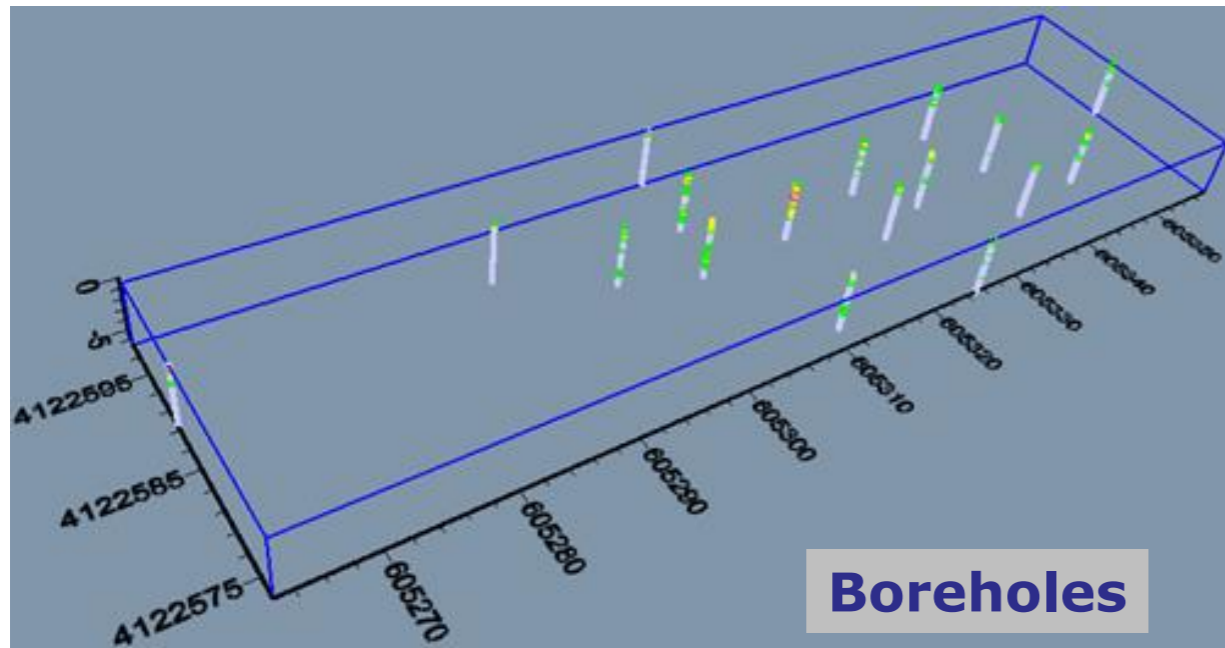
# Sub-soil radiological (0 – 5 m):

321 borehole, 734 samples, 7700 scanning data





# Computation of contaminated volumes: 1 m<sup>3</sup> cell, Isotropic geometry and inverse squared distance approach

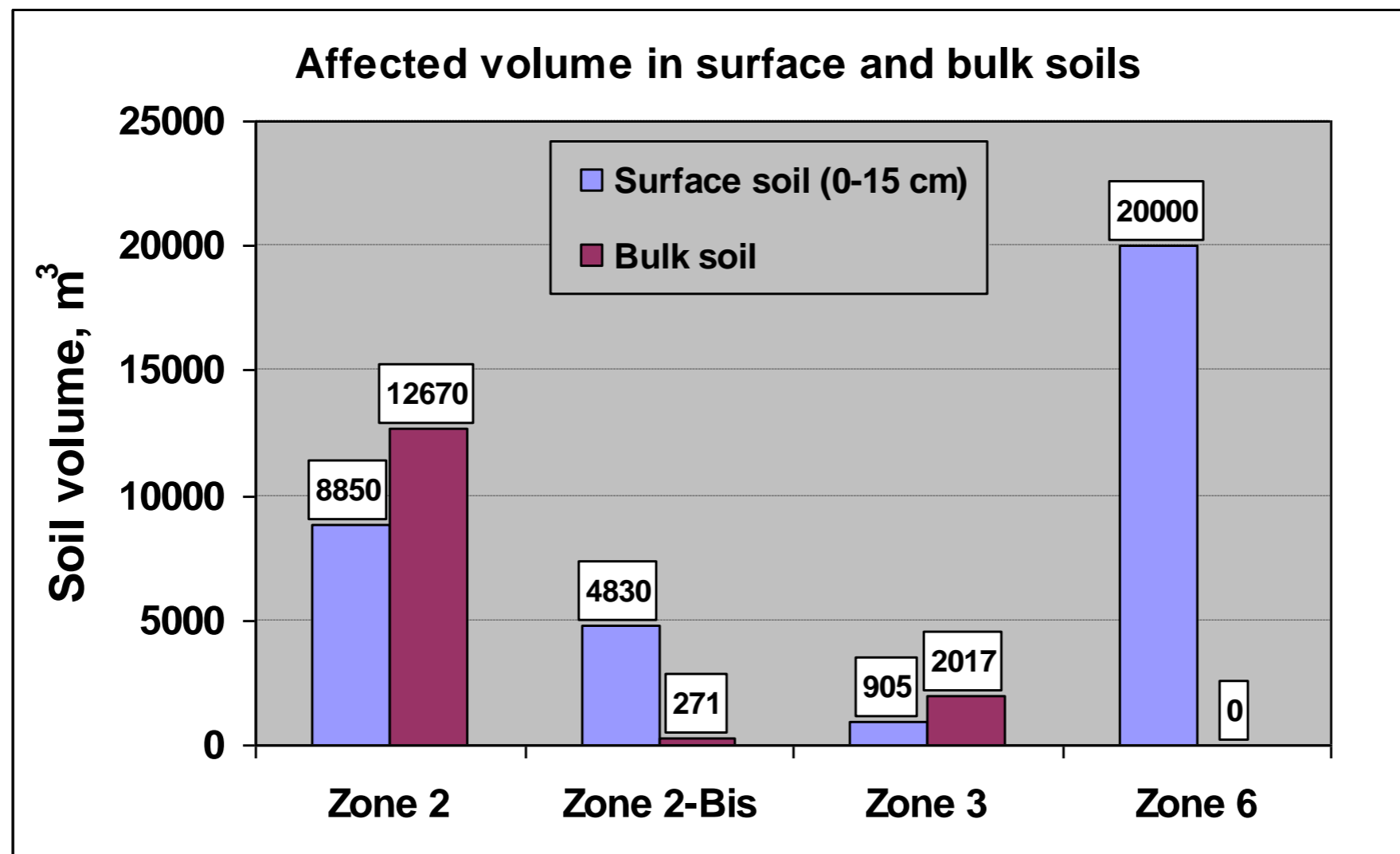




## Computation of contaminated volumes: 1 m<sup>3</sup> cell, Isotropic geometry and inverse squared distance approach

	Zone 2	Zone 2-Bis	Zone 3	Zone 6	Total
Surface of affected topsoil (0-15 cm), m <sup>2</sup>	59,000	32,200	6,035	100,000	197,235
Volume of affected topsoil (0-15 cm), m <sup>3</sup>	8,850	4,830	905	20,000	34,585
Volume of affected subsoil (0.15cm-5 m), m <sup>3</sup>	12,670	271	2,245	0	15,186
Total affected soil, m <sup>3</sup>	21,520*	5,101	3,150	20,000	49,771

(\*) Pit A = 2,270 m<sup>3</sup> Pit B = 669 m<sup>3</sup>





# Estimate of Transuranic inventory from de 1966 accident in Palomares soils at 2019

	Activity <sup>241</sup> Am / GBq				
	Zone 2 North	Zone South	Zone 3	Zone 6	Total
<b>Median</b>	15.5	151	7.04	18.6	193
<b>Quartil 1</b>	12.2	98.6	5.59	14.3	131
<b>Quartil 3</b>	20.7	277	9.84	27.1	335

	Actividad <sup>239</sup> Pu / GBq				
	Zone 2 North	Zone South	Zone 3	Zone 6	Total
<b>Mediana</b>	51.6	505	23.4	62.0	642
<b>Quartil 1</b>	40.8	329	18.6	47.8	436
<b>Quartil 3</b>	69.0	925	32.8	90.4	1117

	Masa <sup>239</sup> Pu / g				
	Zone 2 North	Zone South	Zone 3	Zone 6	Total
<b>Mediana</b>	22.4	220	10.2	26.9	279
<b>Quartil 1</b>	17.7	143	8.10	20.8	190
<b>Quartil 3</b>	30.0	402	14.3	39.3	486

**These amounts of <sup>239</sup>Pu (0.5 kg or 1.1 Tbq) are less than 10% of the inventory estimated from the US-AF Zero Line map prior to the remediation and restoration actions in 1966**

**(6 kg or 13 TBq of <sup>239</sup>Pu)**





Thanks for  
your attention