RÉPUBLIQUE FRANÇAISE
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IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

APPORT DU DRONE A LA PRISE DE DECISION EN SITUATION INCIDENTELLE, ACCIDENTELLE ET POST-ACCIDENTELLE

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Session 12 -15/06/2023

IRSN/PSE-ENV/SIRSE/LER-NORD

SFRP
Société Française de Radioprotection

MEMBRE DE ETSON

SOMMAIRE

- Contexte
- Les drones de l’IRSN
- Les scenarii d’engagement
- Le traitement des données
- Conclusions & Perspectives

IRSN AREAS OF INTERVENTION

IRSN IS THE FRENCH PUBLIC EXPERT ON NUCLEAR AND RADIOLOGICAL RISKS

NUCLEAR SAFETY AND SECURITY

Reactors, fuel cycle, waste management, transport of radioactive materials, radioactive sources

PROTECTION OF THE POPULATION AND THE ENVIRONMENT

Against the risks associated with ionizing radiation

NUCLEAR AND RADIOLOGICAL EMERGENCY RESPONSE

Operational support capacity

SIRSE activities

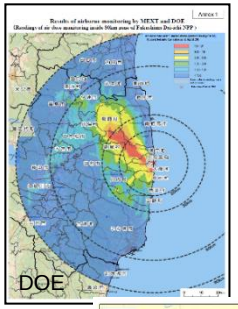
ENVIRONMENTAL MONITORING

RADIOLOGICAL CHARACTERIZATION/ INTERVENTION

EMERGENCY PREPAREDNESS

Systems dedicated to measure radioactivity at different scales

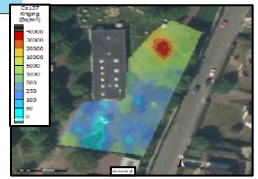
National/region area



Territory

Roads

Lot/Field



Ponctual measure

IRSN DRONE FLEET

PHANTOM 4 by DJI (x2)
- Flight duration: 25 mn
- Visualization : 4K full HD camera

Radioactivity detector:
- ISYFlighter sensor (ISYMAP)
- γ dose rate meter: CsI(Tl)
- Dose rate only
- Dose rate: 1 µSv.h^{-1} to 10 mSv.h^{-1} (*)
- Energy range: 59 keV to 2 MeV

Drone + sensor deployment:
2 people – ~10 mn

UAV dedicated to visualization and dose rate estimation

IRSN video credit 2022

IRSN DRONE FLEET

DRONESTAR 850V2 by INNOVADRONE

MADE IN FRANCE

INNOVADRONE

- Flight duration: 20 mn
- Weight: 8.5 kg (payload capacity of 3.3 kg)
- RTK GPS
- Map a soccer field size during 1 flight

Radioactivity detector:

- SPIR-EXPLORER sensor (MIRION Technologies)
- γ spectrometer NaI + 2 GM tubes
- Dose rate: 0,1 µSv.h^{-1} to 10 Sv.h^{-1}
- Energy range: 50 keV to 3 MeV
- Identification: 100 nSv.h^{-1} of ^{137}Cs in 1s

Drone+sensor deployment:
3 people – 30 mn

UAV dedicated to radioactivity measurement

IRSN video credit 2021

IRSN DRONE FLEET

SURVEYOR by INNOVADRONE

MADE IN FRANCE

- Weight: 8 kg (payload capacity of 3.5 kg)
- Flight duration: 35 mn

Radioactivity detector:

- SPIR-EXPLORER sensor (MIRION Technologies)
- γ spectrometer NaI + 2 GM tubes
- Dose rate: 0,1 µSv.h^{-1} to 10 Sv.h^{-1}
- Energy: 50 keV to 3 MeV
- Odometry system
- Range finder

UAV dedicated to radioactivity measurement

IRSN ENGAGEMENT SCENARII

RADIOACTIVE MATERIAL TRANSPORT ACCIDENT (RMTA)

ORPHAN SOURCE & MALEVOLENT ACT (OSMA)

NUCLEAR FALLOUT (NF)

POLLUTED SITE & SOILS (PSS) R&D

1- IRSN ENGAGEMENT SCENARIO :

RADIOACTIVE MATERIAL TRANSPORT ACCIDENT (RMTA)

SCENARIO A

- RMTA with or without package spillage outside the vehicle, no visible degradation of the package
- Source term: irradiation
- Needed for: intervention preparation, zoning, intervention estimated dosimetry
- Equipment: DJI PHANTOM 4 + ISYFlighter sensor, UAV + SPIR-EXPLORER sensor
- **Results: visualization and dose rate estimation at the closest, dose rate mapping at 1 m from the soil surface**

Scenario A

SCENARIO B

- RMTA with package spillage outside the vehicle, with visible degradation
- Source term: dispersion of radioactive material, radioactive contamination of the environnement
- Needed for: no material spillage evidence, quantify spreading for remediation
- Equipment: DJI PHANTOM 4 + ISYFlighter sensor, UAV + SPIR-EXPLORER sensor
- **Results: visualization, dose rate mapping or relative counting rate, map of the integrated activity per unit area in Bq/m² (naturals & artificials)**

Scenario B

2- IRSN ENGAGEMENT SCENARIO :

ORPHAN SOURCE & MALEVOLENT ACT (OSMA)

SCENARIO A

- OSMA: hidden irradiating source in an outdoor crowded area
- Source term: irradiation
- Needed for: accurate source localization, identification of the radionuclide(s), intervention preparation, zoning, intervention estimated dosimetry
- Equipment: DJI PHANTOM 4 + ISYFlighter sensor, UAV + SPIR-EXPLORER sensor
- **Results: visualization and dose rate estimation at the closest, dose rate mapping or relative counting rate, gamma spectrometry in hover flight from afar and radionuclide id. (no quantification), dose rate mapping at 1 m from the soil surface**

SCENARIO B

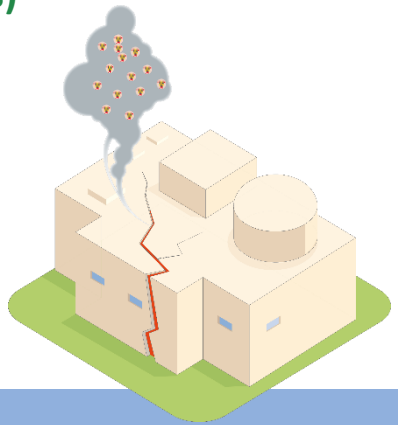
- OSMA: hidden irradiating source plus radioactive material spreading in an outdoor crowded area
- Source term: dispersion of radioactive material
- Needed for: accurate source localization, identification of the radionuclide(s), intervention preparation, quantify spreading for remediation
- Equipment: DJI PHANTOM 4 + ISYFlighter sensor, UAV + SPIR-EXPLORER sensor
- **Results: visualization, dose rate mapping or relative counting rate, gamma spectrometry in hover flight from afar and radionuclide id. (no quantification), map of the ground surface activity per unit area in Bq/m² (artificials)**

3- IRSN ENGAGEMENT SCENARIO :

NUCLEAR FALLOUT (NF)

SCENARIO

- NF: massive release (according to measurement strategy), evaluate localy the level of pollution in the soils, usually deployment of airborne or manborne equipments
- Source term: irradiation of nuclear fallout, radioactive pollution or deposits (mines, industries, etc.)
- Needed for: quantification of dose rate level, quantification of the ground surface activity per unit area
- Equipment: UAV + SPIR-EXPLORER sensor
- **Results: dose rate mapping at 1 m from the soil surface, map of the ground surface activity per unit area in Bq/m² (naturals & artificials)**



IRSN R&D SITE:

POLLUTED SITE & SOILS (PSS)

SCENARIO

- PSS (R&D): Expertise of polluted site, usually deployment of airborne or manborne devices
- R&D site: testing of equipment, flight procedures and data treatment methods
- Source term: irradiation of nuclear fallout
- Needed for: identify areas of interest, estimate ground surface activity and potentially the activity per unit mass massic of the soil (hypothesis)
- Equipment: UAV + SPIR-EXPLORER sensor
- **Outcomes: determination/optimization of parameters for calculus of dose rate at 1 m from the soil surface, Mirion software Spir Wizard parameters' optimization, map of ground surface activity per unit area in Bq/m² (naturals & artificials) or map of the activity per unit mass at the soil surface in Bq/kg (naturals and artificials)**

WORK IN PROGRESS

DETERMINATION & OPTIMIZATION OF PARAMETERS FOR DOSE RATE AT 1 M HEIGHT CALCULUS MEASUREMENT ON A NATURAL SITE WITH NATURAL RADIONUCLIDES (CAMARGUE, FRANCE)

Site description

- Beach site: contamination with Uranium, Thorium
- Simple topography
- Large surface of water nearby

Challenges

- How to determine the height above the ground with a good accuracy:
  - UAV range finder measurement is influenced by the topography
  - Low precision of free Global Digital Elevation Model data sources (SRTM)

Development in progress

- Access to the Global Digital Elevation Model with good accuracy that can be used for
  - Autopilot and height control (flight parameters)
  - Data treatment
  - Optimize Mirion software parameters used for the dose rate calculus at 1 m height. Adjust parameters to enhance accuracy.
  - Estimate useful parameters to interpret drone results (field of vision, sensitivity of key parameters, uncertainties). Help in the interpretation of results.
  - Compare results from both drone measurement systems. Obtain compatible results from both systems.

WORK IN PROGRESS

DOSE RATE CALCULUS AT 1 M HEIGHT

- The calculus of dose rate at 1 m height is performed by Mirion software SPIR WIZARD. Some of the parameters are adjustable in the software.

- $D_{1m} = D_{net\,;\,local} \cdot h^{n} \cdot e^{\left(\mu_{air;source} \cdot \left(\frac{273 \cdot P \cdot h}{(T+273) \cdot P_{ref}} - h_{ref}\right)\right)} + D_{Cosm\,;local} \cdot e^{(-h \cdot \mu_{Air;cosm})} + D_{Radon} + D_{intrin} + D_{tell}$

with

- $D_{net\,;\,local} = D \cdot f_{amb\,;\,mesu} - D_{Cosm\,;\,mer} \cdot e^{(-Alt \cdot \mu_{Air;cosm})} \cdot f_{cosm\,;\,mesu} - D_{Radon} - D_{intrin} - D_{tell\,;\,local}$

WORK IN PROGRESS

NORMALIZATION OF DATA AT 1 M ABOVE GROUND

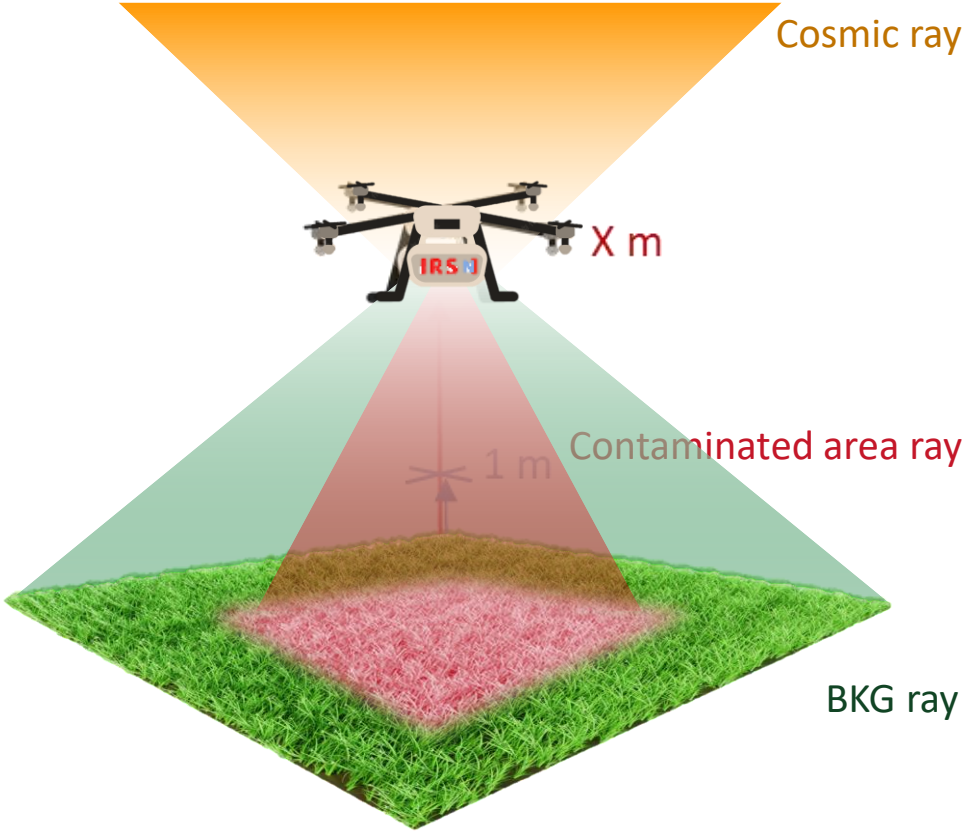
Composition

At 1 m height, dose rate is function of :

- Cosmic ray
- BKG ray
- Contaminated area ray

Each component is different in type, energy, geometry and is related to the flying height

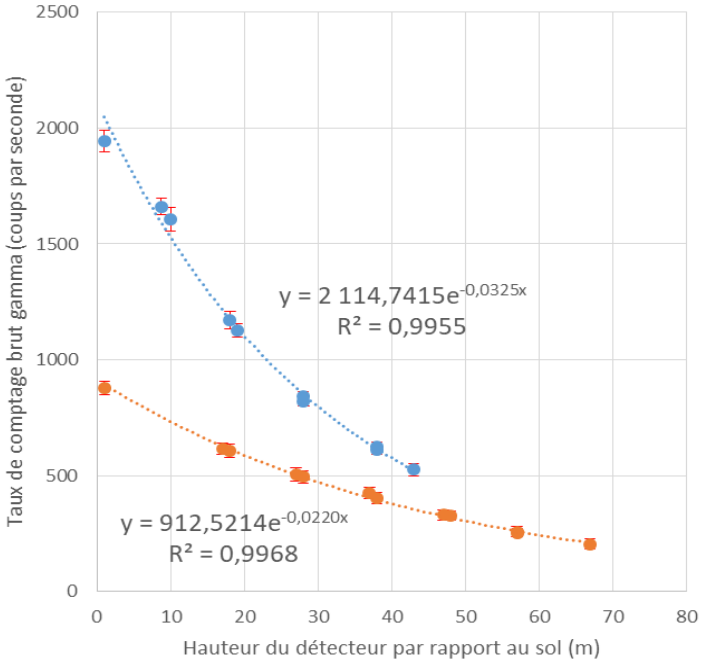
Each component of the signal is analyzed independently

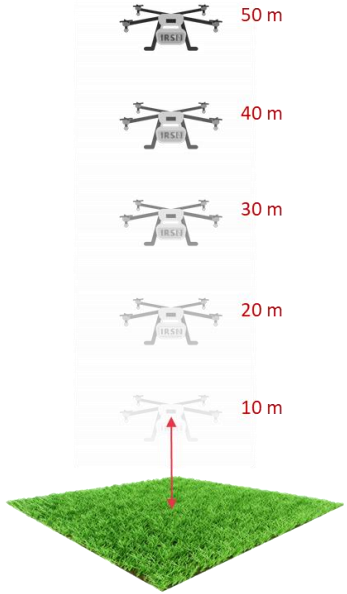


WORK IN PROGRESS

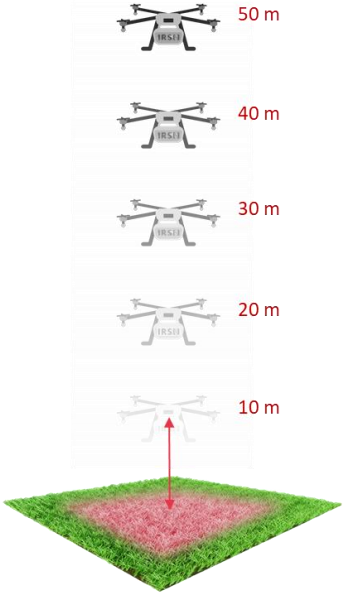
NORMALIZATION OF DATA AT 1 M ABOVE GROUND

- Patch 1: BKG dose rate attenuation
- Patch 2: Contaminated area dose rate attenuation





Patch 1



Patch 2

CONCLUSION

- L'IRSN a acheté des drones pour minimiser la dose des équipes d'intervention, pour avoir une vision globale de la situation (visuel) et récolter des données radioactives. Cette technologie présente de nombreux avantages en termes de temps de déploiement, d'aide à l'organisation et à la préparation des interventions sur le terrain, mais aussi une réelle plus-value sur l'optimisation de la dose collective des équipes d'intervention sur site.

- L'IRSN a défini des scénarios d'engagement en cas de crise pour les drones. Pour chaque scénario, des résultats/ des attendus ont été définis.

- Les traitements de données sont en cours afin de rendre les résultats attendus par les différents scenarii.

PERSPECTIVES

- Le développement d'une méthodologie pour calculer le débit d'équivalent de dose à 1m du sol : généralisation de l'utilisation de la technique des chandelles à différentes hauteurs sur des points contaminés et non contaminés pour optimiser certains paramètres du calcul. Collaborations avec JAEA, le LTD (IRSN)

- Tests et optimisation de la technique d'odométrie sur le nouveau drone pour les vols en extérieur et en intérieur

- Optimisation des paramètres de vol afin d'augmenter la sensibilité du capteur vs. le temps de déploiement du capteur

THANKS FOR YOUR ATTENTION

MERCI POUR VOTRE ATTENTION

QUESTIONS ?

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SCENARII D'ENGAGEMENT DES DRONES - IRSN

	Scenarii	Risques	Besoins	Demandeur/destinataires des données recueillies	Données transmises (résultats)
RMTA	**Avec** déversement de colis **Sans** détérioration du colis	Irradiation	• Préparation intervention • Zonage • Prévisionnel dosimétrique	• Interne IRSN (E. interv) • Interne et externe IRSN • Interne IRSN (E. interv)	• Dose rate at local point • Equiv 1m high doserate mapping
	Avec déversement de colis **Avec** détérioration du colis	Irradiation et contamination	• Localiser la pollution • Quantifier la pollution	• Interne et externe IRSN • Interne et externe IRSN	• Carte débit de dose ou taux de comptage relatif • Carte activité surfacique
OSM	Source irradiante en zone d'affluence	Semi ponctuelle irradiation pure	• Localisation source • Identification • Préparation intervention • Zonage • Prévisionnel dosimétrique	• Externe IRSN • Externe IRSN • Interne IRSN (E. interv) • Interne et externe IRSN • Interne IRSN (E. interv)	• Carte débit de dose ou taux de comptage relatif • Spectrométrie gamma (stationnaire ; sans quantification) • Débit de dose au plus proche • Carte de débit de dose à 1 m • Carte de débit d'équivalent de dose à 1 m du sol
	Source irradiante et dispersée en zone d'affluence	Etendue Irradiation et contamination	• Localiser la dispersion de matière • Identification • Quantifier la dispersion	• Interne IRSN (E. interv) • Externe IRSN • Externe IRSN	• Carte débit de dose ou taux de comptage relatif • Spectrométrie gamma (stationnaire ; sans quantification) • Carte activité surfacique
PAG	SSP	Etendue	• Identifier zones d'intérêts • Quantifier le dépôt	• Interne IRSN (E. interv) • Externe IRSN	• Carte de débit d'équivalent de dose à 1 m du sol • Carte activité surfacique
NA	Rejet massif - objectifs spécifiques de la stratégie de mesure Là où hélicoptère et pédestre non appropriés	Grandement étendue Irradiation et contamination	• Localiser la dispersion de matière • Quantifier le dépôt	• Interne et externe IRSN • Interne et externe IRSN	• Carte de débit d'équivalent de dose à 1 m du sol • Carte activité surfacique

IRSN DATA INTEGRATION SYSTEM

IN SITU

acquisition

analysis

DB

visualization

IRSN scripts

Drone data transfer in real-time on IRSN data base

IRSN BACK OFFICE

Spectra DB

storage

WEB

extraction
visualization
calculation

ARCGIS

AVID

KARTOTRAK

INTERWINNER

EXCEL

MIRION/SMI

MIRION/REPLAY

Results can be processed *in situ* or by IRSN back office

WORK IN PROGRESS

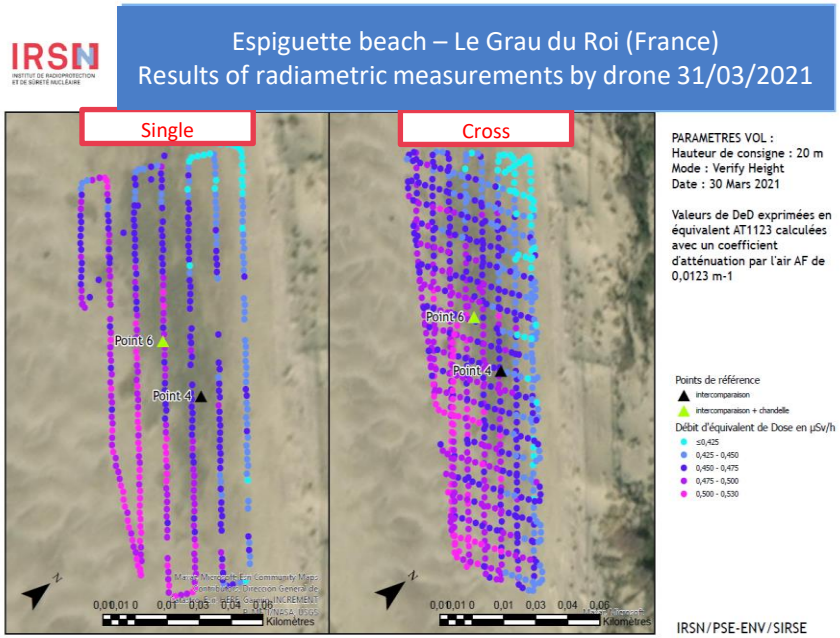
Dronestar – Autopilot Flight parameters

- Flight height above ground: 10 – 30 meters depending on the flight security
- Height control:
  - Constant height above ground measured with the UAV range finder

    → recommended for sites without vegetation or buildings
  - Correction of the height above ground at each waypoint (change point direction) with Digital terrestrial Elevation Model (DEM) from NASA

    → recommended for sites with vegetation or buildings

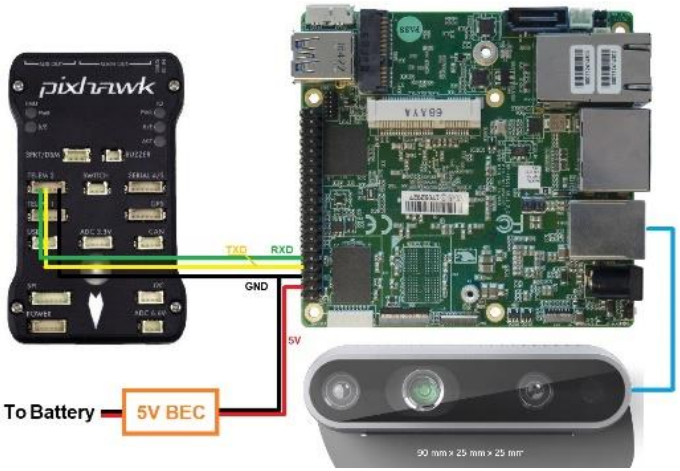
    → development in progress to use Digital Elevation Model throughout the flight
- Speed: 1 to 3 $m.s^{-1}$ depending on the size of de site, the composition of the source and its extent
- Track mode: cross in order to offset few losses of data
- Interval: around 5 m depending on the flight height



NEW DEVELOPMENT: INDOOR GEO POSITIONING

- Radiological mapping indoor or when bad GPS positioning
  - Allowing drone flight stabilization and automatic drone piloting
  - Recovering radiological measurement data with geo positioning and GIS exploitation

- Integration of an additional module of indoor geo positioning using inertial visual odometry



WORK IN PROGRESS

EXAMPLE: MEASUREMENT ON A CONTAMINATED SITE WITH NATURAL RADIONUCLIDE (FRANCE)

Site description

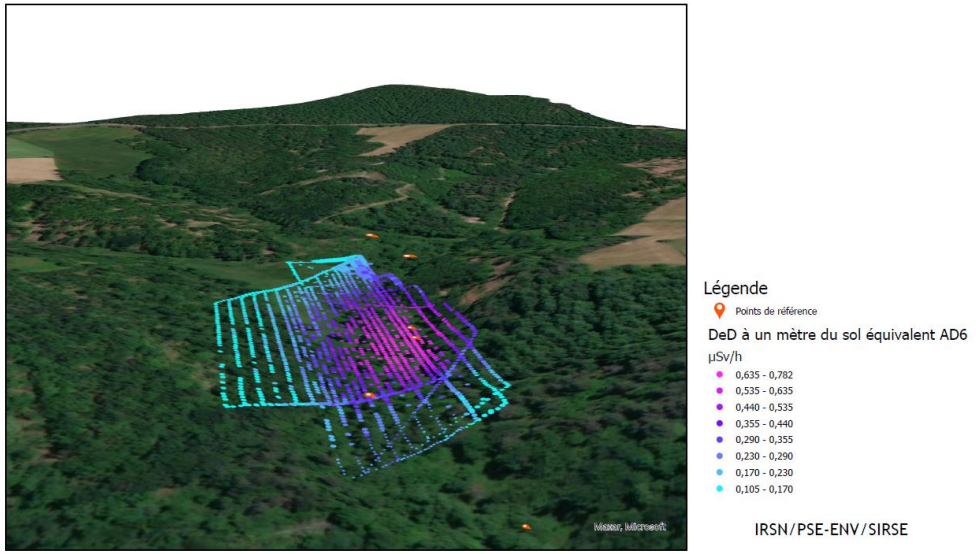
- Former mining site: contamination with Radium-226
- High and dense vegetation with rugged topography
- Harsh flying conditions

Challenges

- How to determine the height above the ground with a good accuracy:
  - ➢ UAV range finder measurement is influenced by the forest canopy
  - ➢ Low precision of free Global Digital Elevation Model data sources (SRTM)

Development in progress

- Access to the Global Digital Elevation Model with good accuracy that can be used for
  - ➢ Autopilot and height control (flight parameters)
  - ➢ Data treatment



WORK IN PROGRESS

EXAMPLE OF DRONE DEPLOYMENT: PSS
MEASUREMENT ON A NATURAL SITE WITH NATURAL RADIONUCLIDES (CAMARGUE, FRANCE)

Site description

- Beach site: contamination with Uranium, Thorium
- Rugged topography
- Large surface of water nearby

Challenges

- How to determine the height above the ground with a good accuracy:
  - ➢ UAV range finder measurement is influenced by the topography
  - ➢ Low precision of free Global Digital Elevation Model data sources (SRTM)

Development in progress

- Access to the Global Digital Elevation Model with good accuracy that can be used for
  - ➢ Autopilot and height control (flight parameters)
  - ➢ Data treatment

Paramètre	Valeur recommandée
Vitesse de déplacement	3 $m.s^{-1}$
Hauteur de vol	15 mètres [2]
Gestion de la hauteur	Mode “Relatif + Verify Height” (solution B) [2] Ou Mode “Terrain” (solution C)
Maillage	Cross grid = activé Distance between line = 5 m Overlap et Sidelap = 0% Mine lane separation = 0 Optimise for distance = activé