Measurement and data analysis concepts combined with data assimilation techniques for source term reconstruction and dose assessment

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Outline

- *Introduction*
- *Radiological measurement systems in Europe and Germany*
- *Introduction of spectroscopy detector systems*
- *Update of the German Measurement Programme*
- *Ground Contamination Maps*
- *Data Assimilation & Inverse Modelling*

Introduction

The combination of measured data from stationary ambient dose equivalent rate (ADER) monitoring systems and stationary and mobile in situ gamma-spectrometry systems have been the basic elements of the monitoring concept in Germany since many years.

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Recently new concepts have been introduced aiming to improve of radiation protection strategies:

- ADER detectors with spectroscopy capability.
- Insitu measurements independent from ADER stations of the network.
- Deployable ADER probes
  - to enhance the density of ADER monitoring stations in areas close to the location where a release is expected to potentially take place.

Introduction

Nuclide specific ground contamination maps can be generated based on on-line monitoring data from

- stationary and deployable ADER probes (including spectroscopic data)
- aero-gamma and
- car-borne systems.

In the early phase of an emergency situation, the ability to combine prognostic data and measured data is important to

- understand the radiological situation,
- identify affected areas and
- assess the dose for the public and task forces.

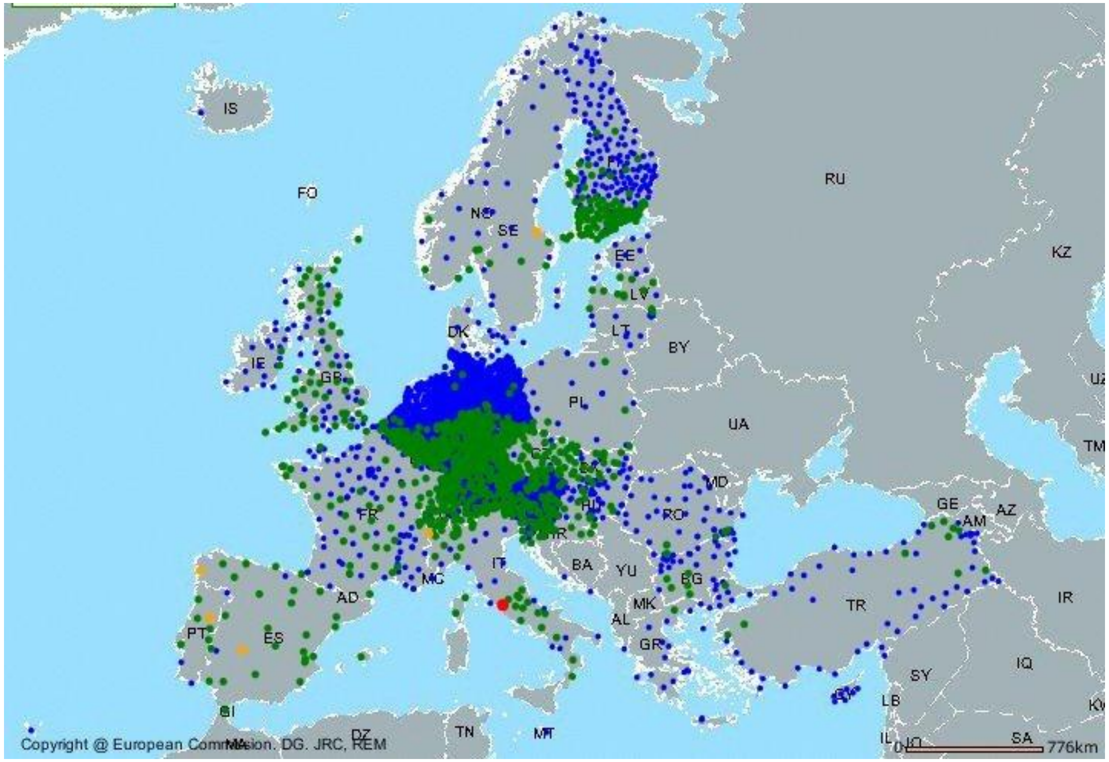
Different research projects are aiming on source term reconstruction using monitoring data in the vicinity of nuclear power plants.

Ambient Dose Equivalent Rate (ADER) networks in Europe

European countries established ADER networks during the cold war periode and improved these networks after the Chernobyl accident in 1986.

Today there is still a non negligible potential of nuclear hazards with respect to:

- **nuclear facilities**
- **atomic bomb scenarios**
- **terroristic attacs**



European ADER networks

- 33 nations
- 67 networks
- 4500 stations

Since 15 years GDR data are exchanged between all EU member states continuously in routine and emergency using the **EURDEP** (EURopean Data Exchange Platform) and recently via IRMIS – IAEA world wide platform

Purpose of ADER Networks

Main purpose of ADER networks in an emergency situation:

– to detect contamination of the environment during release and in post-release phase
– to assess resulting dose to man
– to provide fast and reliable information to decision makers

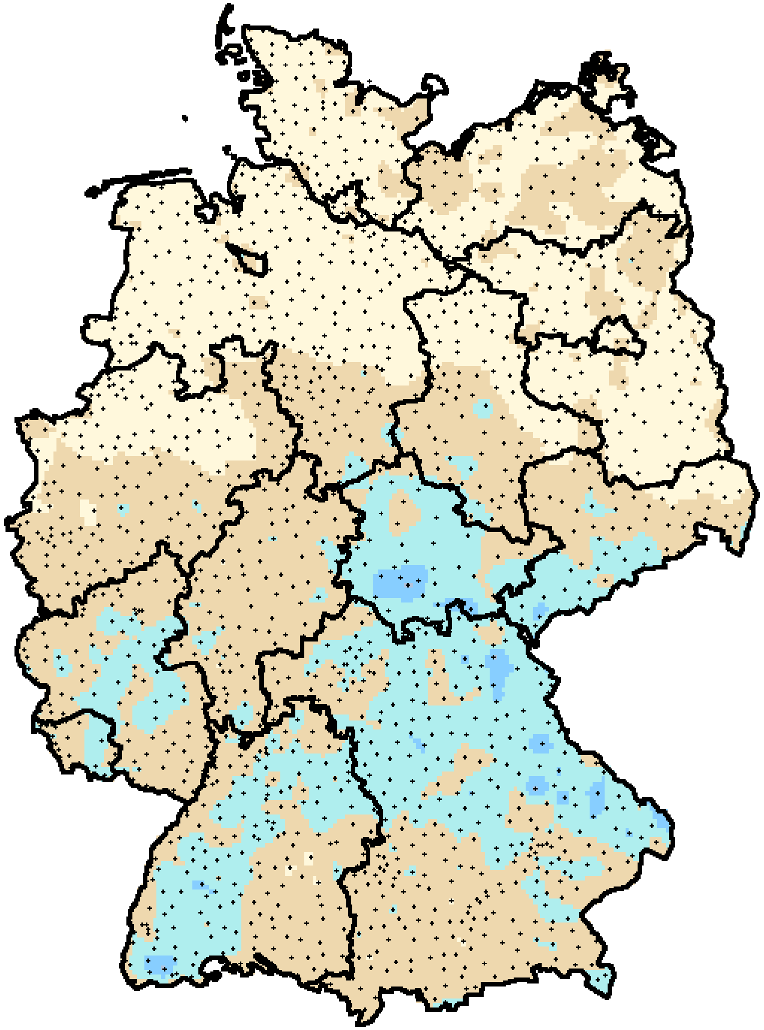
What must decision makers know:

– areas affected -> ADER network & mobile systems
– strength of the contamination -> ADER network & mobile systems
– relevant nuclides ?
– actual and future exposure of men in the affected areas -> ADER network & mobile systems

Improvements of ADER network (release and post release phase):

– sampling data from all stations in 10 minutes
– integration of spectroscopy detectors

German ADER network



1800 ADER stations

Distance:
25 km : mean
8 km in the 25 km area around NPPs

Measured data:

Area Ambient dose equivalent rate every 10 minutes

Range: 50nSv/h-5Sv/h

2 Geiger-Müller tubes
1m above ground

ADER above threshold:

station will generate an early warning

Normal conditions, release and post-release phase

Stationary in-situ systems (HPGe detectors)

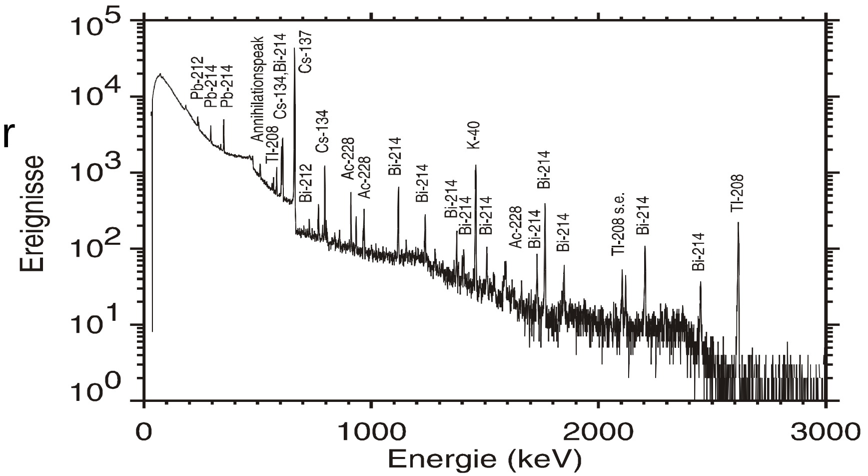
BfS operates one in-situ detector at the Schauinsland continuously since October 2004,
10% HPGe electrically cooled with 1m above ground.

German weather service (DWD) operates 40 similar stationary in-situ systems
(data transmission every 2 hours).

ADER network and in-situ systems are operated continuously during normal conditions, release and post-release phase. For higher spatial resolution, mobile equipment is required

Post release phase
insitu gamma spectrometry

Purpose:
- high resolution gamma spectroscopy
- Nuclide specific ground contamination maps for long-lived radionuclides (e.g. Cs-137)



Number of insitu systems in Germany:
- 6 BfS
- 17 Federal states
- 3 KHG

Coordination:
- BfS coordinates all 23 insitu systems (BfS and Federal States)

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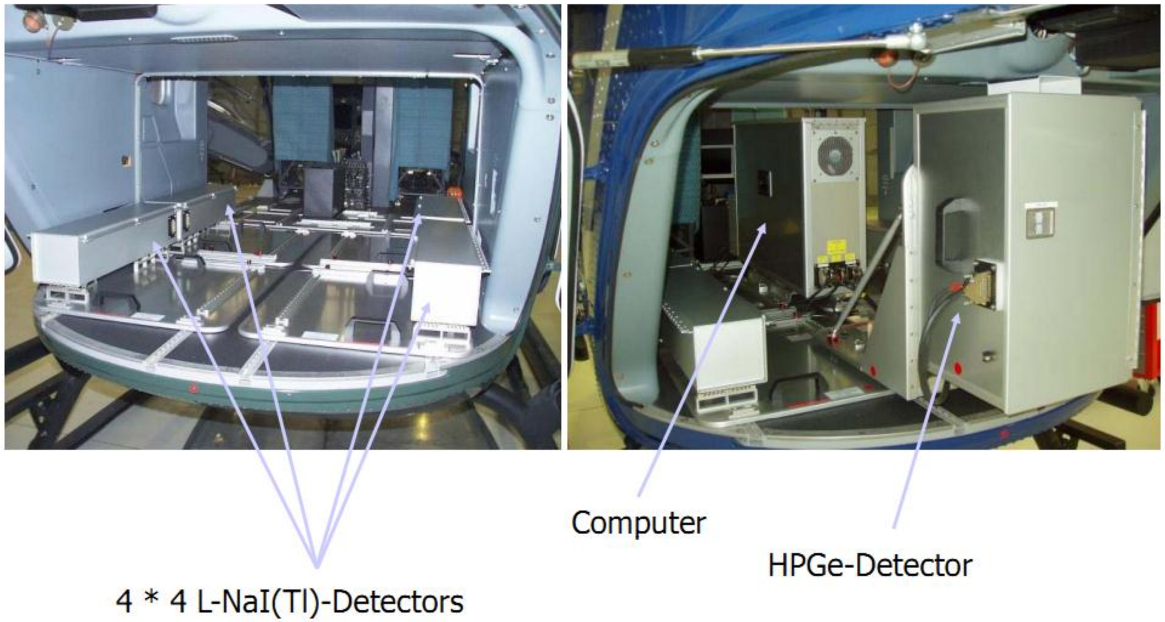
Post release phase

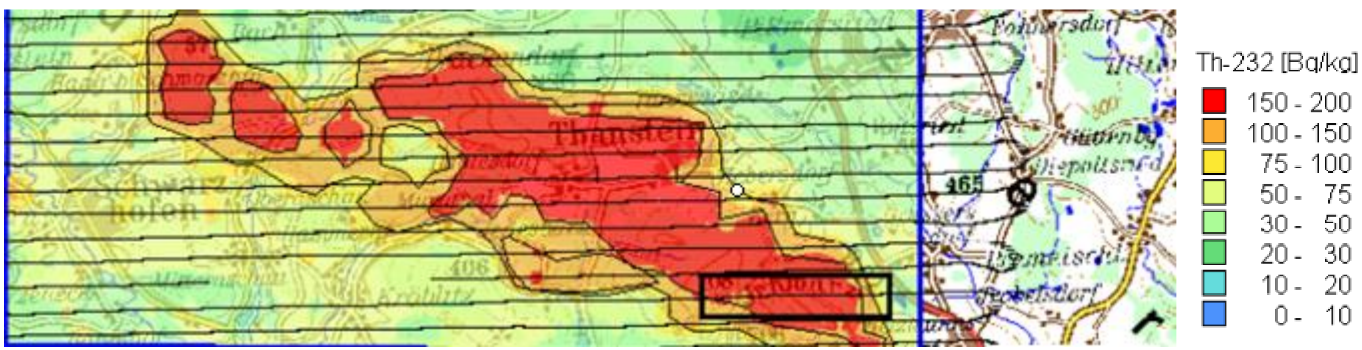
Aero gamma – helicopter based systems

Setup of the german airborne measurement system



Purpose:
To identify small scale inhomogeneities of ground contamination

Speed – above 100 km/h / 65 kt
Altitude - above 90 meters / 300 ft
Line spacing - 370 meters / 0.2 NM
Maximum line length - 15 km



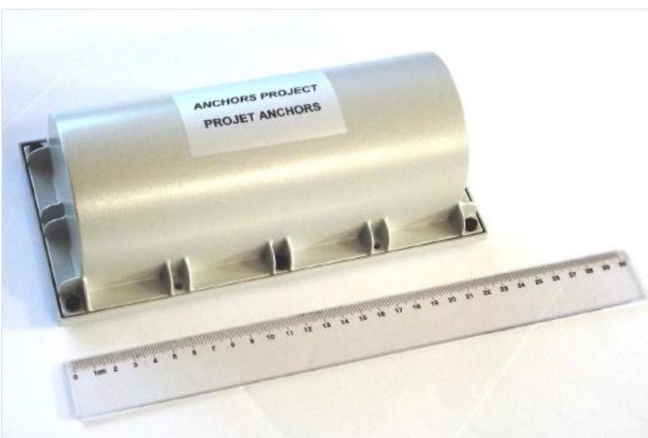
Post release phase

Aero gamma – Drone based systems

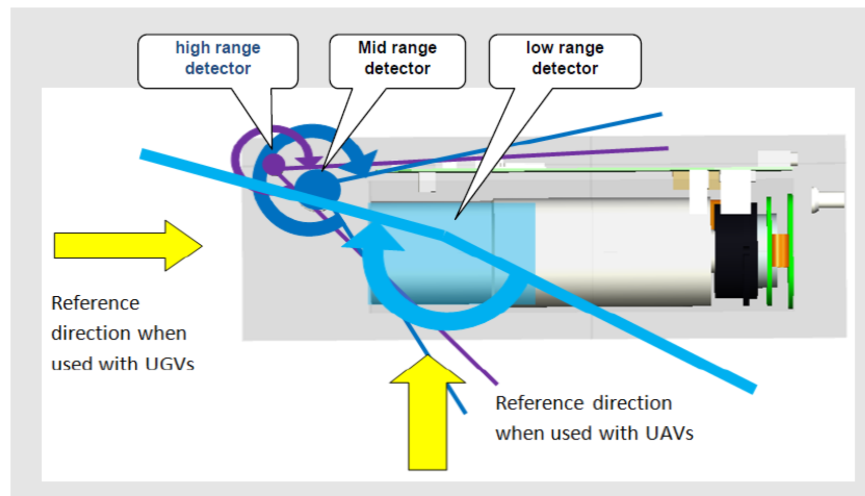
Requirements for detection and measurement (from ANCHORS project)

Dose rate measurement range: BKG to 10Sv/h
Accuracy in reference conditions: <10%
Angular effect: <20% (Cs137) over 270°
Detection threshold: 0,1µSv/h over BKG in 2s

Radiological requirements for spectroscopy
Energy range 50keV to 3MeV
1024 channels, 16bit per channel, spectrum every second



Other requirements
Supply voltage : typical 6V, power consumption: <2W
RS-232 115kBd
Maximal weight: 800g
Temperature range: -20°C to 40°C
Protection level: at least IP54, desirable IP65
Vibrations: resistant to vibrations induced by UAVs.
Total integrated dose of 10Sv



Duration of the French/German ANCHORS project 3 years
End of project: April 2015

Post release phase

Mobile, vehicle based systems in urban areas

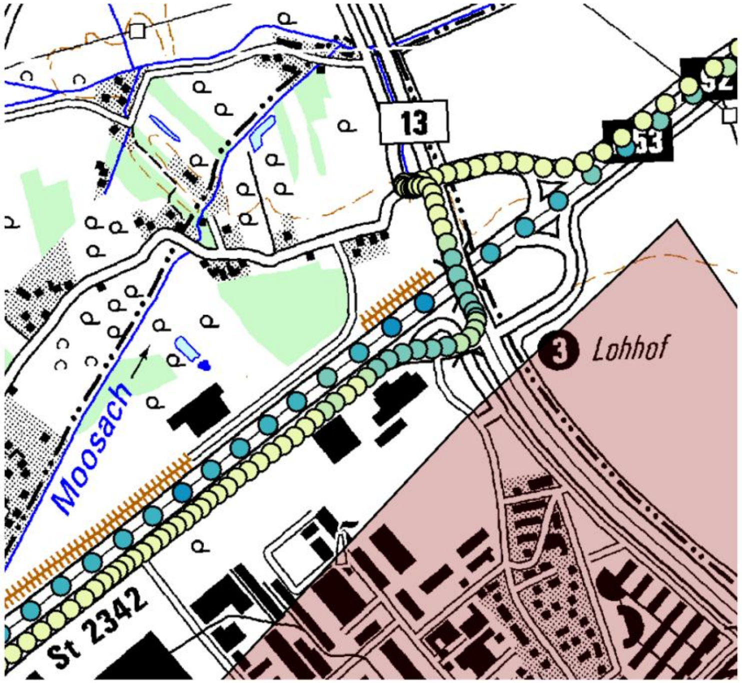
Mobile teams with large volume scintillation detectors

- Gamma dose rate

- poor energy resolution allows to compare count rate in high and low energy window -> artificial radiation

- Position via GPS

Purpose:
To identify small scale inhomogenities of ground contamination in urban areas



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New Concept
Introduction of “deployable” probes in 2014

Temporary deployment of probes enables higher density of monitoring stations in relevant areas

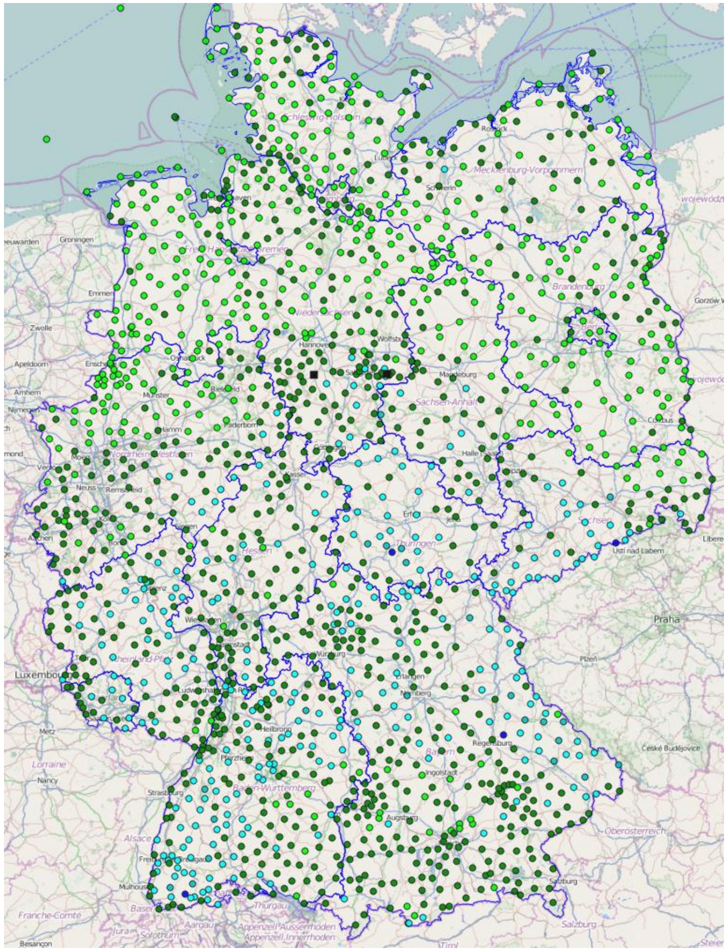
Relevant locations will be determined based on RODOS and ATM calculations

Up to 20 probes are available at BfS and can be deployed at any time on demand

Measurement exercise in 2014 at Neunburg vorm Wald (Oberpfalz)

Stationary ADER probe   Deployable ADER probe

New in-situ measurement concept



In-situ measurements always have to be performed parallel to ADER measurements.

The Nuclide vector is determined by in-situ measurements. ADER is used to interpolate to other ADER stations without in-situ data.

Measurements are performed every 3 years on ADER stations. The nuclide specific background is known.

But in-situ measurements are limited to locations of the ~1800 ADER stations.

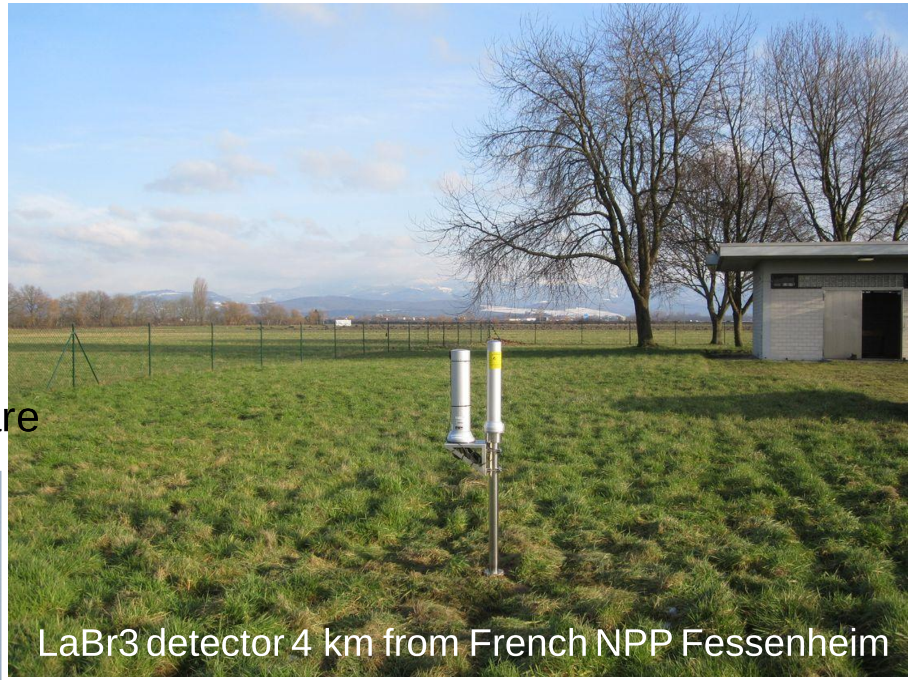
In the new concept, in-situ measurements can be performed at any location. In addition ADER measurements are performed with mobile ADER probes.

The new concept requires changes of the measurement procedure and the software application

Introduction of spectrometric ADER detectors

BfS started to investigate spectrometric detectors in 2004

- Legal requirements
- First test based on commercial MCAs and detectors
- Integration and improvement of the hardware components
- Development of tailored hardware and software



LaBr3 detector 4 km from French NPP Fessenheim

CZT based system at Brocken Mountain since 2006

• First CZT based system was installed on the Brocken mountain in 2006,
• LaBr3 based system installed at the Schauinsland mountain in 2008,
LaBr3 based system in the vicinity of French NPP Fessenheim operated since February 2015.

General requirements of spectroscopy detectors

Following German legislation, sensitivity and spectrometric capabilities shall assure the detection of a homogeneous surface contamination of Cs-137 with an activity of

Sensitivity:
1kBq/m^2 within 30min: dose rate: ~1nSv/h above natural background
- crystal size > 3 cm^3

Energy resolution:
To deconvolve a Chernobyl / Fukushima like spectra:
- energy resolution < 2.0 % @ Cs-137

Maximum dose rate:
From RODOS simulations
- ADER in the vicinity of NPP in the 50 mSv/h up to 1 Sv/h range

Compact Gamma Ray Spectrometers

The Kromek GR1 and Ritec micro SPEC are gamma ray spectrometers utilizing CZT detectors with built-in preamplifier, shaping amplifier, baseline restorer, pulse height digitizer, and HV supply. The detectors are connected to a PC via USB.

BfS has purchased 6 Kromek detectors with energy resolution between 1.5 and 2.0 keV and integrated in standard ADER probe

Specifications

CZT-detector in mm3	1000	1500
Detector type	CPG	hemispherical
Energy range in keV	30 - 3000	20 - 3000
Energy resolution FWHM @ 662 keV [%]	1.3 - 2.5	1.7 - 2.5
Upper dose rate range [mSv/h]	3	4
Maximum throughput [kcps]	30	100
Number of channels	4096	2048
Integral non-linearity [%]	< ± 0.02	<0.3
Temperature range		0 – 40°C
Temperature drift [% / °C]		<0.02
Integrated temperature sensor	No	Yes
Power consumption [mW]	250	500
Dimensions [mm3]	25x25x63	25×25×70
Weight [g]	60	80

microSPEC Gamma Ray Spectrometer

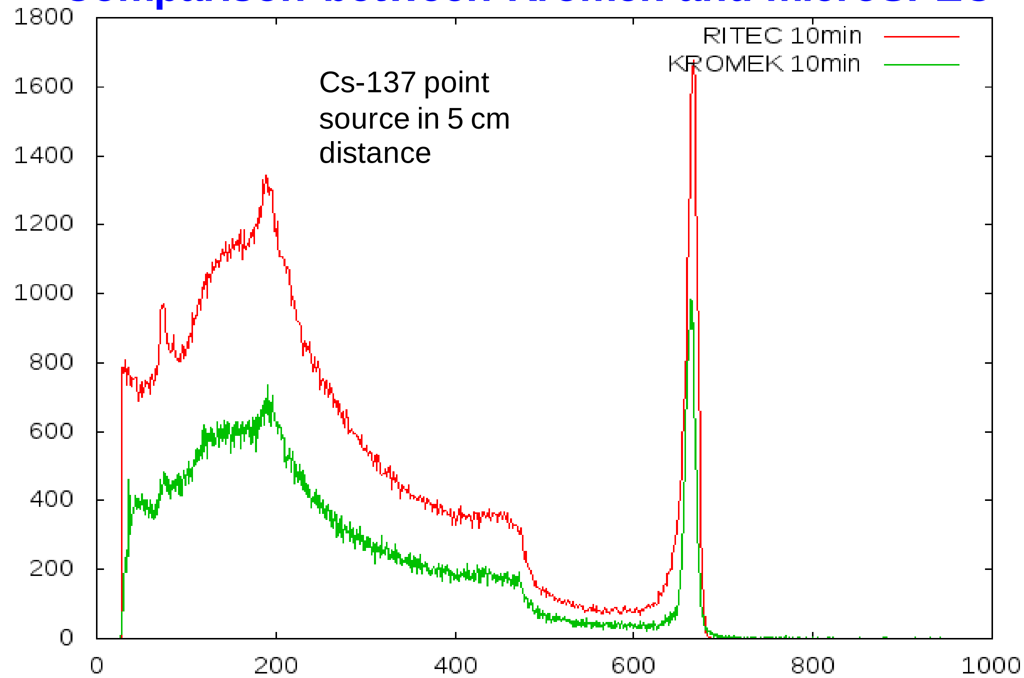
BfS has purchased 6 Kromek detectors with energy resolution between 1.5 and 2.0 keV and integrated in standard ADER probe

BfS has obtained one microSPEC with energy resolution between 1.5 and 2.0 keV for testing

Maximum dose rate range of microSPEC

Volume mm3	Max ADER mSv/h	Peak/ Compton
1500	**4**	**8.3**
1000	8	7.5
500	12	6.6
60	100	5.3
14	400	4.4
5	**900**	**4.3**
1	3500	2.6

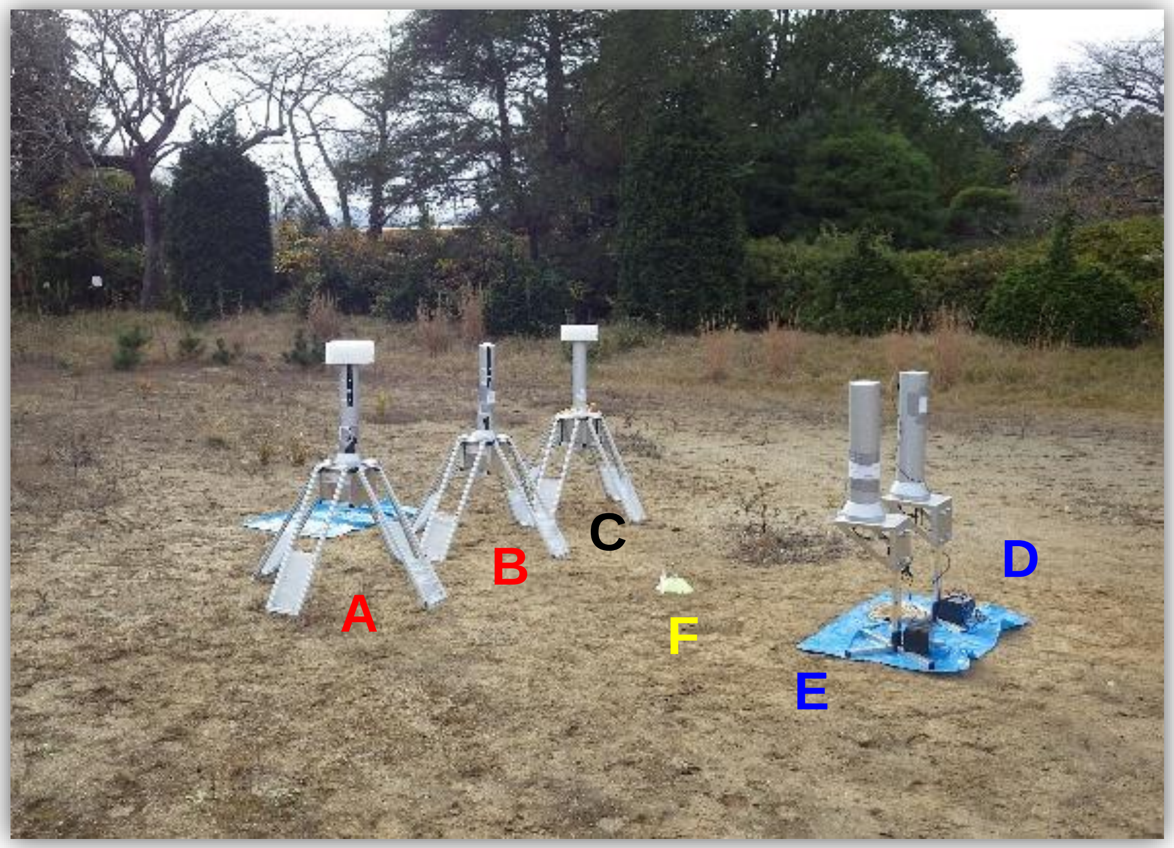
Comparison between Kromek and microSPEC



Energy / keV

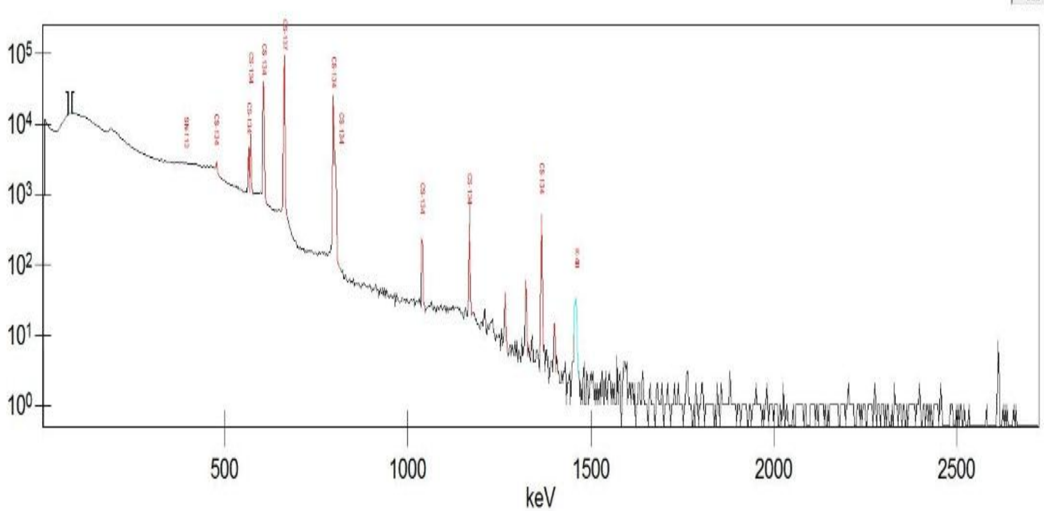
Comparison of different spectroscopy ADER probes during RANET-2014 Workshop in Fukushima

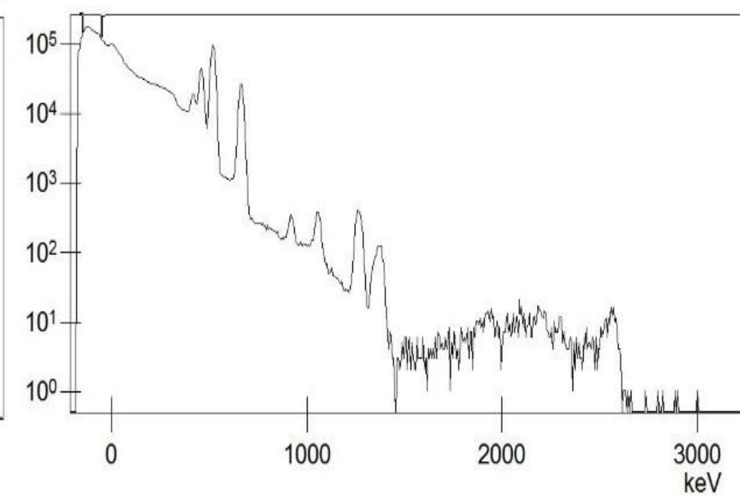
Stationary Probes at MPJP-KumamaciES-01	ODL [µSv/h]
A = GS08x-2 (Kromek)	15,2
B = GS08x-1 (Kromek)	14,9
C = GS08 (standard probe)	15,0
D = Spectrotracer 2 (Labr3)	14,8
E = Spectrotracer 1 (Labr3)	14,2
F = Insitu (HPGe)	-



Comparison between insitu (HPGe) and spectroscopy ADER (LaBr3) probes during RANET-2014 Workshop in Fukushima

Stationary Probes at MPJP-KumamaciES-01	Cs-134 [Bq/m2] (B=0)	Cs-137 [Bq/m2] (B=0)	Ratio
Insitu (HPGE)	0,66E+06	2,06E+06	3,12
D = Spectrotracer 2 ($LaBr_3$)	0,65E+06	2,00E+06	3,08
E = Spectrotracer 1 ($LaBr_3$)	0,71E+06	2,22E+06	3,13





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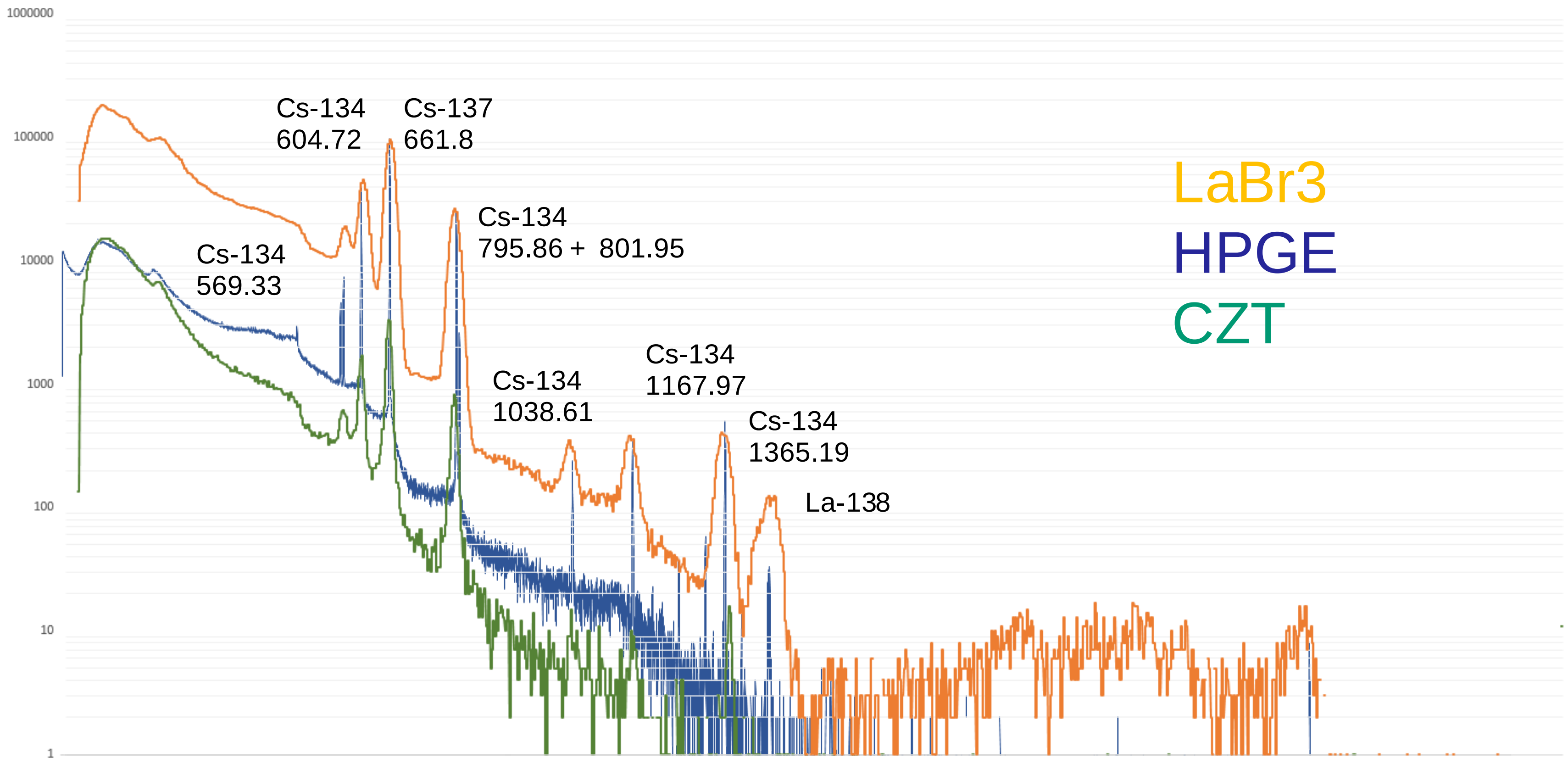


Ground Contamination Tool

Deposition mapping by dose rate and in situ gamma spectrometry data

- Main purpose of the Ground Contamination Tool is the determination of ratios between ADER and relevant radionuclides at those locations where **both**, ADER and nuclide specific information is available.
- This allows to estimate the nuclide specific concentration at locations where only ADER is measured.
- Shortly after cloud passage phase, the method enables large area contamination mapping

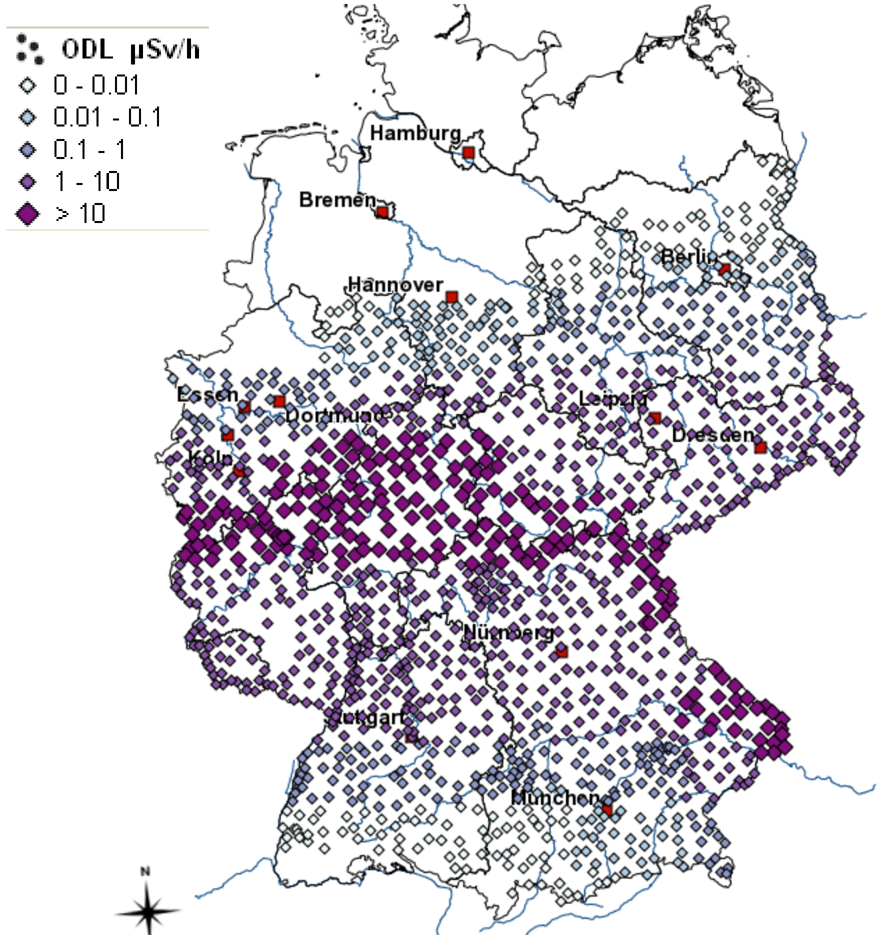
- Step 1: **Supporting points** (ADER and insitu data from measurements):
  - Net dose rate: ADER
  - Activity on ground for nuclide i (from in situ data): AG(i)
    Nuclide vector: $f(i) = AG(i) / ADER$

- Step 2: **Interpolation points** (only at locations where ADER data are measured)
  - Spatial interpolation of nuclide vector f(i)
  - Net dose rate: ADER (derived from measured dose rate)
  - Assessment of activity deposited on ground

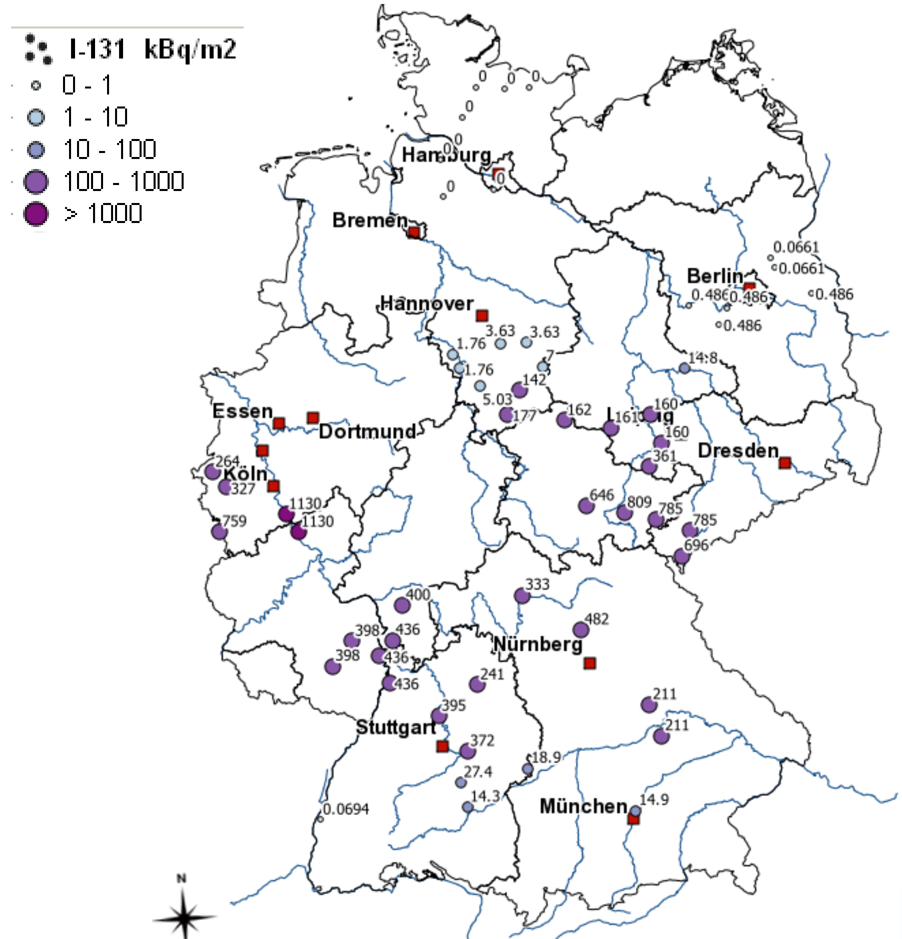
$$AG(i) = f(i) \{AEDR – ADER(BG)\}$$

Ground Contamination Tool
IMIS exercise with simulated data instead of real data

For monitoring stations:
Simulated net dose rate



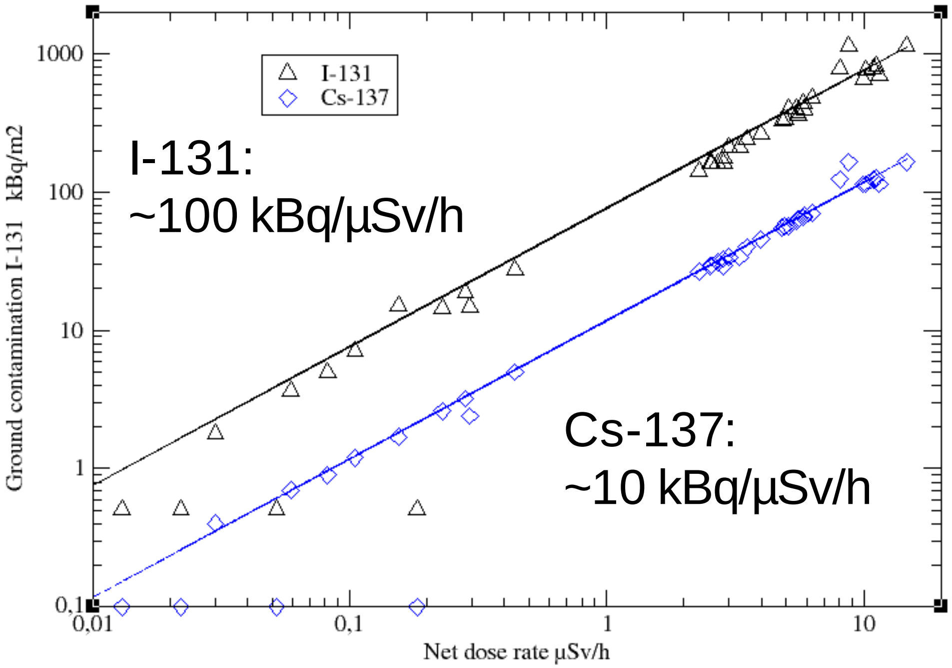
For locations with 50 real measurements:
Simulated I-131 activity



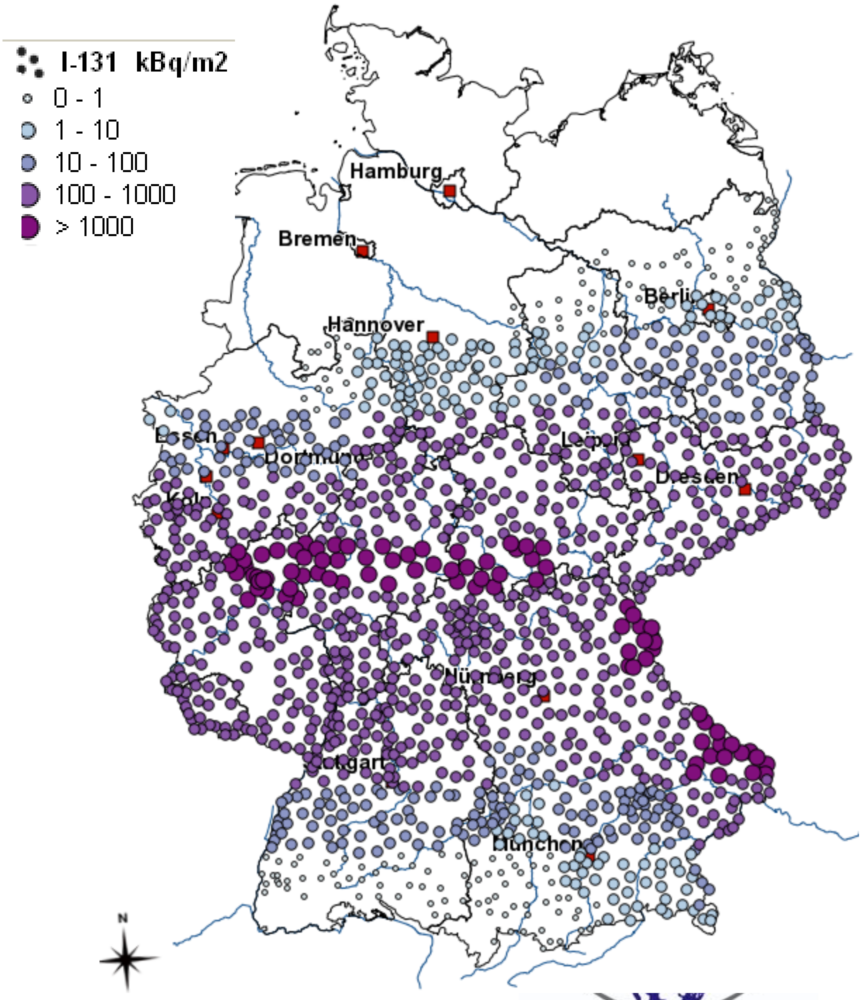
Ground Contamination Tool

IMIS exercise with simulated data instead of real data

Correlation of net dose rate and activity deposited on ground



Assessed I-131 Activity



The method enables timely large area contamination mapping in the first days after an accidental release event

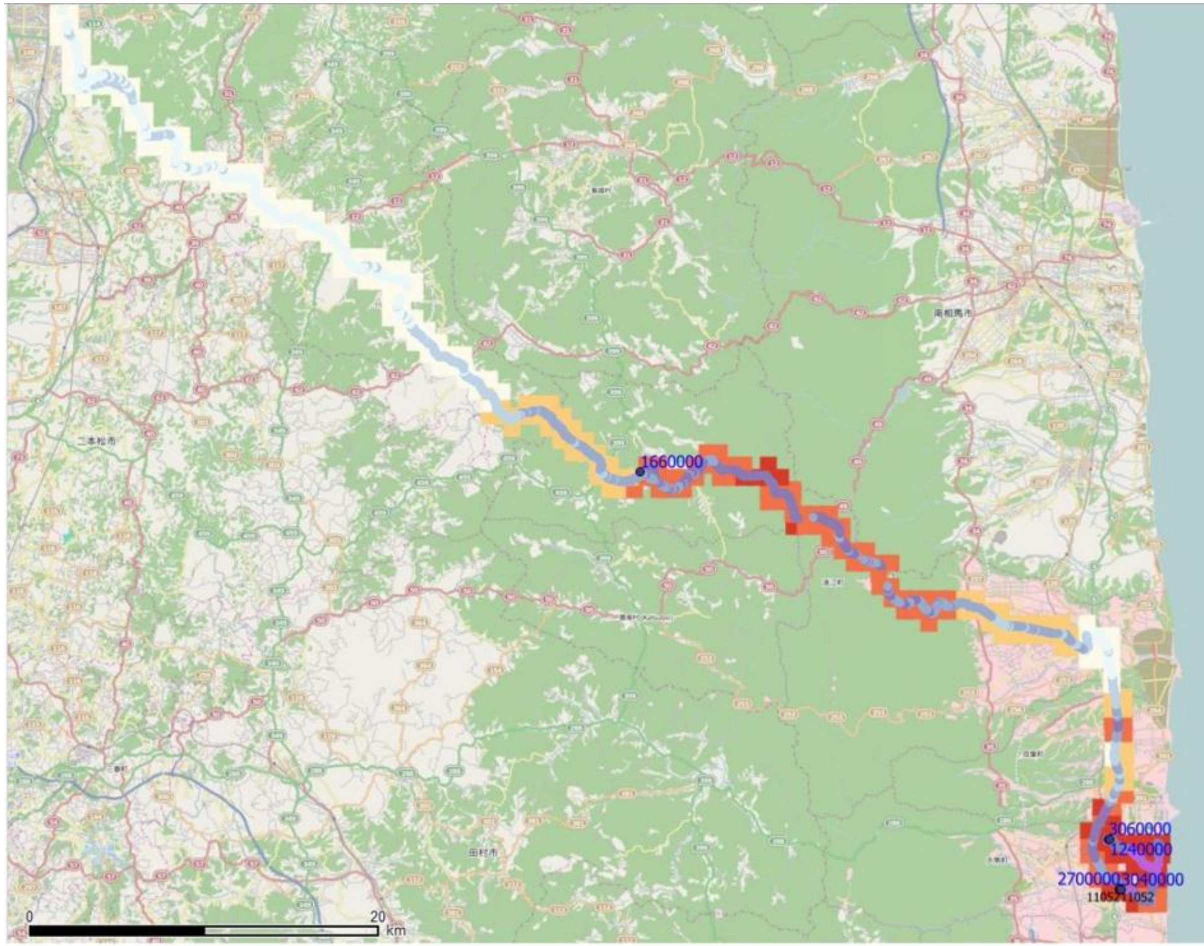
Ground Contamination Tool
Data from RANET-2014 Workshop in Fukushima

Ground Contamination Tool applied for Cs-137 and Cs-137 in the Fukushima Daichi area

Location	Cs-134 [Bq/m2] B=1	Cs-137 [Bq/m2] B=1	ADER[µSv/h]	ratio	CS137/ADER	CS134/ADER
2014-11-18						
MPJP-KumamachiES-05	9,74E+05	3,04E+06	12,6	3,12	241270	77302
MPJP-OkumaPlayPark-XX	9,86E+05	3,06E+06	15,5	3,10	197419	63613
MPJP-OkumaPlayPark-01	4,01E+05	1,24E+06	5,9	3,09	210169	67966
2014-11-20						
MPJP-OkumaJuniorHS-01	7,14E+05	2,20E+06	10,8	3,08	203704	66111
MPJP-OkumaJuniorHS-03	7,38E+05	2,30E+06	10,8	3,12	212963	68333
MPJP-OkumaJuniorHS-05	5,17E+05	1,60E+06	8,79	3,09	182025	58817
MPJP-KumamaciES-01	1,17E+06	3,67E+06	17,5	3,14	209714	66857
MPJP-KumamaciES-02	1,14E+06	4,41E+06	20,9	3,87	211005	54545
MPJP-KumamaciES-04	1,34E+06	4,23E+06	18,8	3,16	225000	71277
			Mean	**3,2**	**210363**	**66091**
			Stand.Deviation	0,2	16553	6653
			relative Difference	0,07	0,08	0,10

Ground Contamination Tool
Data from RANET-2014 Workshop in Fukushima

Ratio Cs-137/ADER = 210363 Bq/m² / μSv/h (relaxation length 1cm)



Fukushima Prefecture
17 – 21 November 2014

ADER in 10^{-6} Sv/h
- <0.3
- 0.3 - 1
- 1 - 3
- 3 - 10
- 10 - 30
- > 30

Cs-137 Ground contamination in 1000 Bq/m²
- < 100
- 100 - 300
- 300 -1000
- 1000 - 3000
- > 3000

Cs-137 Ground contamination data from HPGe in Bq/m²

Measured data from DE-FAT-1
Car-borne monitoring
between 2014-11-18T00:00:00Z
and 2014-11-18T07:00:00Z

by DE-EBS-1

Bundesamt für Strahlenschutz

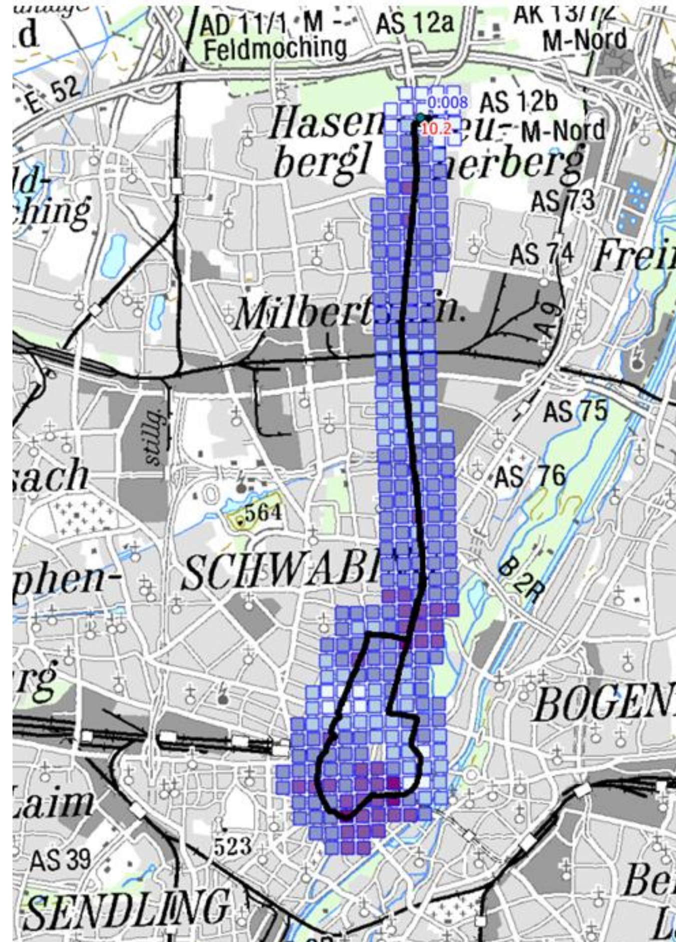
Ground Contamination Tool
Integration of data from vehicle based dose rate probes

Vehicle based dose rate measurements
(6 BfS Systems)

- mobile teams with plastic scintillator
- measured dose rate every second
- position detection via GPS
- natural background rejection algorithm

Application of the method for the determination of contaminations in urban areas near release or with small scaled contamination patterns (wet deposition)

- Investigated area: about 30 km per unit and hour
- Dose rate ~ 0.1 µSv/h
- Calculated Activity ~ 20 kBq/m^2 Cs-137 + Cs-134

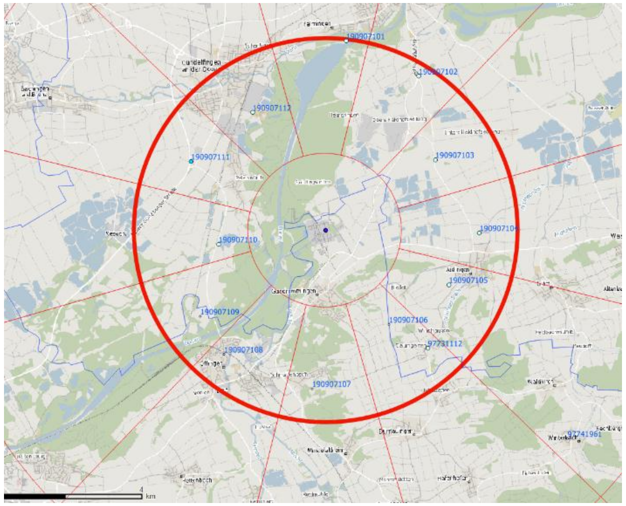


Update of the Measurement Programme following the Recommendations of SSK

Following an investigation by BfS considering a release phase of several days and meteorological conditions for all German NPPs over the periode of one year, the German radiation protection commission (SSK) developed new recommendations in 2014:

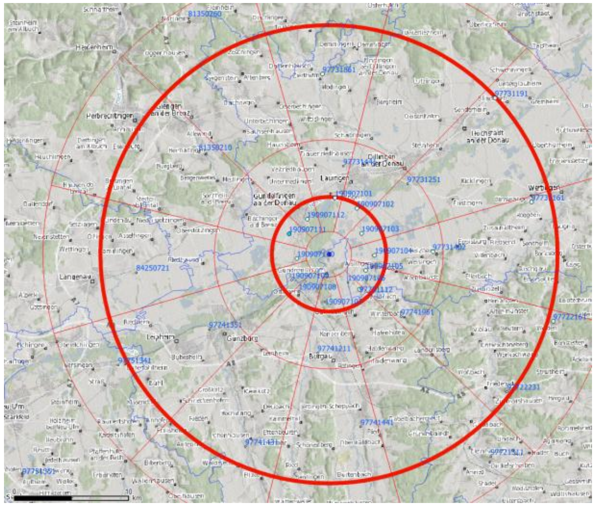
- New planning areas
- Situation dependent measurement and sampling programme
- Consideration of extended duration of accident

Inner Zone



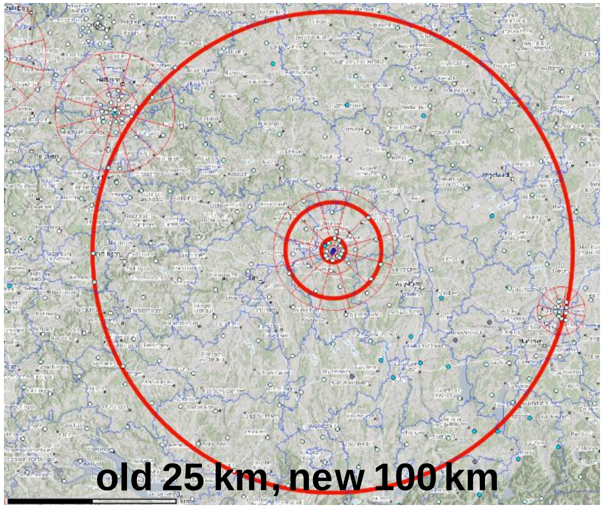
old 2 km, new 5 km

Central Zone



old 10 km, new 20 km

Far Zone



Update of Planning Zones and Measurement Programme

1) New planning areas

2) Situation dependent measurement and sampling programme

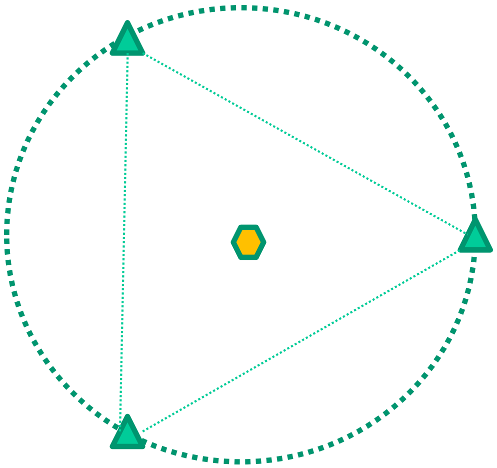
- Flexible measurement programme depending on the development of the event:
  - number and frequence of measurements/sampling .
- Stationary ADER probes or measurements with mobile equipment in inhabited areas
  - One probe in villages with more than 5000 inhabitants:
  - Number of probes in villages with more than 20,000 inhabitants: depending on size and topography.

3) Consideration of extended duration of accident

Measurement strategy and coordination of measurement teams has to consider:

- Extended duration of the accident,
- Changes of meteorological conditions,
- Safety of measurement teams,
- during release phase interventions by mobile teams in **central zone** have to be avoided.

4) source term assessment



3 spectroscopy probes in 0.5 to 1 km distance from NPP allows source term assessment in most situations

Requirements on Measurement Equipment

Different requirements depending on the planning zones

Requirements for probes installed inside the central zone (< 5 km)

- robustness against flooding, earthquake and extreme weather conditions
- one week autonomouos operation of the probes
- redundant data communication infrastructure (fixed line modem and satellite communication)

Requirements for probes installed outside the central zone (> 5 km)

- 72 hours autonomouos operation of the probes
- redundant data communication infrastructure:
  - fixed line modem or GSM/G3 communication and USB memory stick for data storage

Installation of spectroscopy probes in all zones with ADER range selected in accordance with expected dose rate levels:

- Central Zone 100 nSv/h - 1000 mSv/h
- Middle Zone 50 nSv/h - 10 mSv/h,
- Far Zone 50 nSv/h - 1 mSv/h.

Data Assimilation & Inverse Modelling

NILU Norsk institutt for luftforskning Norwegian Institute for Air Research

Bundesamt für Strahlenschutz

TÜV SÜD Industrie Service — Mehr Sicherheit. Mehr Wert.

Research Project 3612S60026 by BfS

Diagnosis and prognosis of the evolution of a radiological relevant incident in a nuclear facility using source term estimation based on measured data in the environment

Status January 2015

Data Assimilation & Inverse Modelling
Objectives of the Research Project

Development of a computer code which

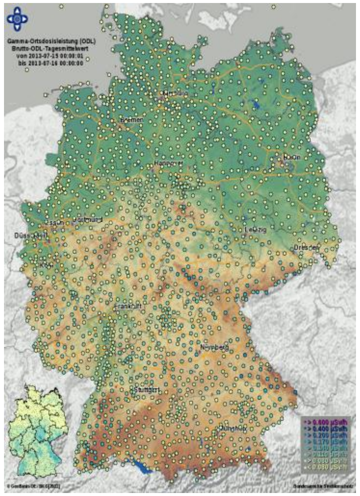
- **estimates a source term** based on radiological measurement of dose rates and/or nuclide specific activity concentrations in the environment of a nuclear facility emitting radioactivity into the atmosphere during a nuclear incident
- **gives a diagnosis of the plant state** based primarly on this backward calculated source term
- **offers a prognosis of the plant state evolution** and source term evolution based on the diagnosis

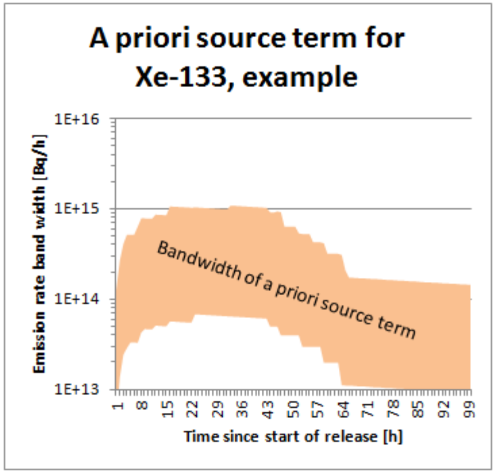
Data Assimilation & Inverse Modelling
Principle of the methode

Input Data

Input data consist of the following three independent data sets:

- **Time dependent measurements** of dose rates or nuclide specific activity concentrations in the atmosphere or on ground in the environment of the radioactivity emitting nuclear facility.
- **„A priori“ source term**: Rough estimation of a source term with bandwidth, using information about the plant and the incident, if available (so called „a priori“ data).
- **Weather data** in the environment of the nuclear facility (past for inverse calculation and future for prognosis).





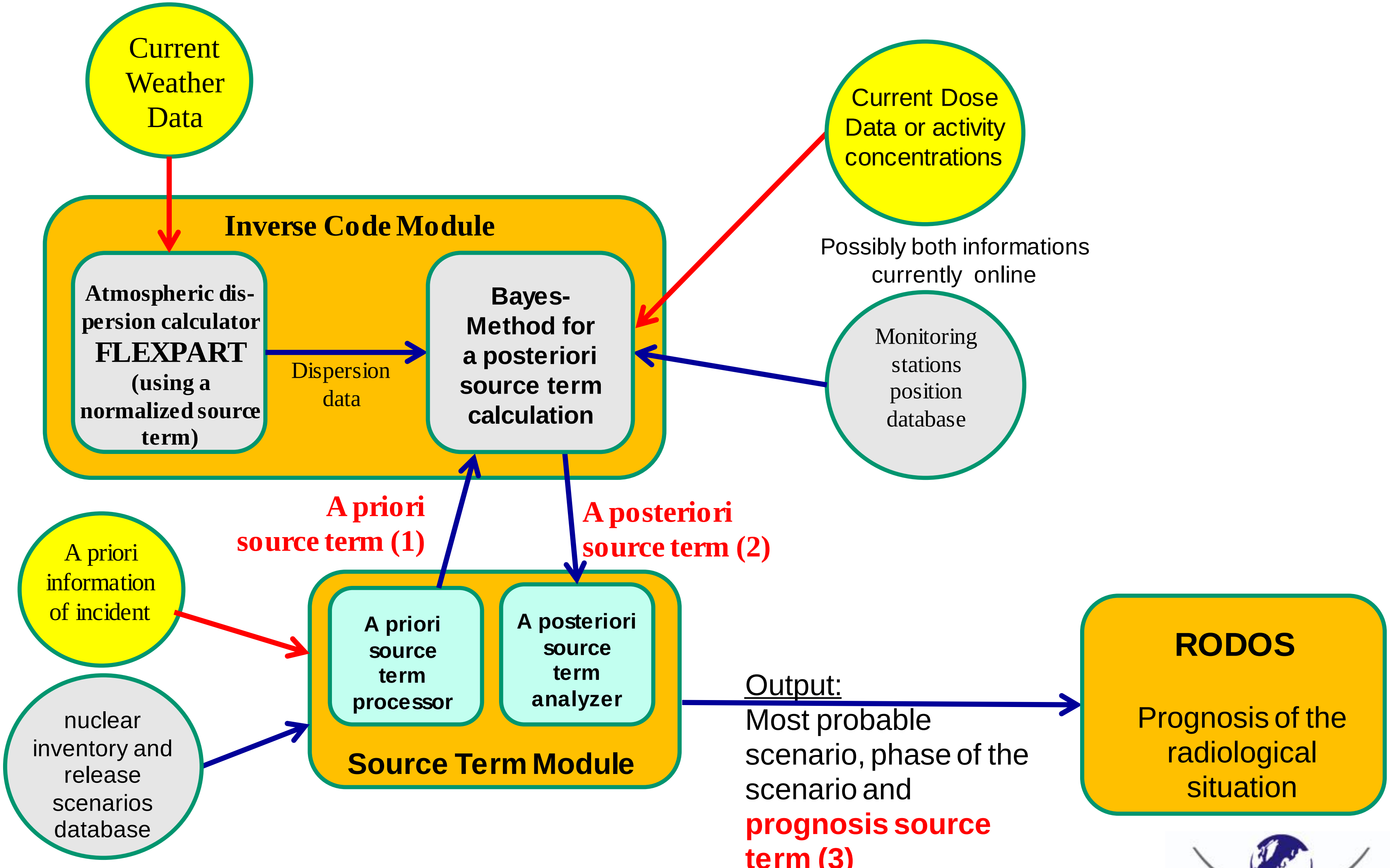
Data Assimilation & Inverse Modelling
Principle of the methode

Computing steps:

Using these data sets, following steps are carried out:

- Atmospheric dispersion/transport calculation for a normalized source term using the weather data,
  → **creation of dispersion data**.
- Calculation of a refined source term („**A posteriori source term**") via a Bayes method. I. e. the a priori source term is modified and refined on the basis of radiological measurements and the dispersion data.
- Comparison of the refined source term with source terms from a source term data base (preferably from PSA Level 2 studies) of incidents of the nuclear facility concerned (**A posteriori source term analysis**).
- Best maches between the a posteriori source term and the source terms from the data base will be used for a **plant state diagnosis**.
- Source terms from the database will be used for a **prognosis of the radiological situation**.

Data Assimilation & Inverse Modelling
Modules and interfaces of the computer code



Status / Next Steps

Status:

- Definition of interfaces between measured data, dispersion calculator and inverse code
- Implementation of the modul for calculating the „a priori“ source term
- Implementation of inverse method for radionuclide concentrations and dose rate (Fortran 90)
  - Upgrade and new implementation of the consisting inversion algorithm for a multi radionuclide spectra
  - Adaption of the code for user-friendly application
  - Implementation of a modul for dose rate and introduction of the module into the inversion algorithm
- Implementation of a modul for analyzing the a posteriori source term and giving a prognosis of the source term evolution
- Current documentation of method and code
- Sensitivity studies by use of simulated source term data

Next steps

- Optimizing the codes
- Implementation of a nuclear inventory and release data base
- Development of an interface file format to transfer measured dose rate data to the inverse code
- Test of the complete code with simulated data


Thank you