Procedures for the Release of Sites

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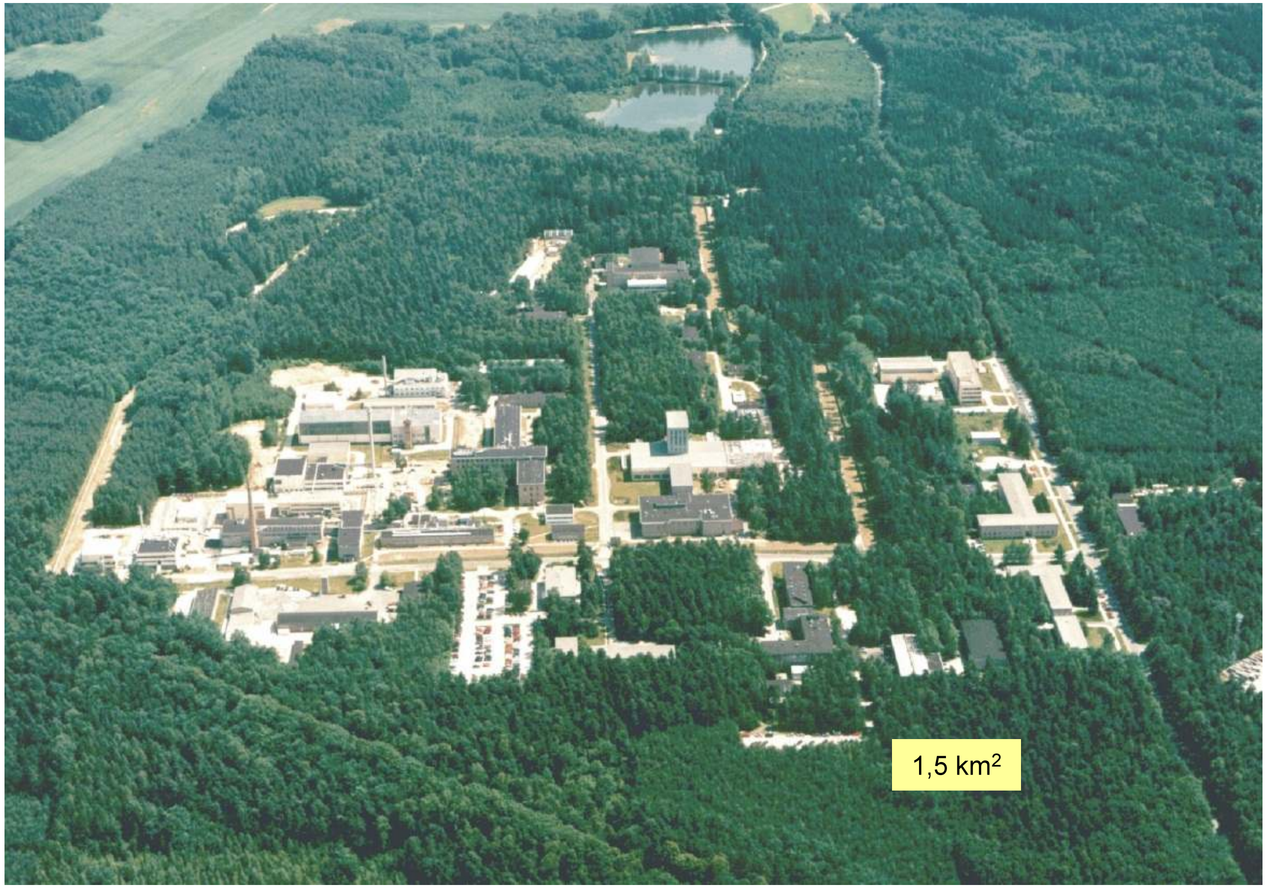


content

•steps of radiation survey process
•measurement methods
•sampling and analysis
•determination of “nuclide fingerprint” or “nuclide vector”

sources:

•MARSSIM

“Multi-Agency Radiation Survey and Site Investigation Manual” (USA)

•standards (international and national)

•experiences in release of buildings sites

- Rossendorf
- reactors (NPP and research)
- uranium mining and milling sites
- other nuclear installations

Radiation survey and site investigation process

radiation survey and site investigation process

6 principal steps:

1. site identification
2. historical site assessment
3. scoping survey
4. characterisation survey
5. remedial action support survey
6. final status support survey

site identification:

- typical performed before decommissioning
- known use of radioactive material
- potential former use of radioactive material
- environmental settings
    - geology
    - hydrogeology
    - hydrology
    - meteorology

collection of the knowledge about the installation

particularly:

- kind of installation
- historic and current usage
- system boundaries
- buildings
- materials
- activated and contaminated areas
- migration pathways
  - water cycles
  - waste and waste water
  - steam
  - aerosols
  - dust
  - leakages

sources:

- licenses, permits, authorisations
- operating records
- interviews
  - current employees
  - previous employees
- site reconnaissance

evaluation of historical site assessment data

identify:

- potential contaminants
- potentially contaminated areas
- potentially contaminated media
    - surface soil
    - subsurface soil and media
    - surface water
    - ground water
    - air
    - structures

potential contaminants (examples)

- activation nuclides:
  - beta: H-3, C-14, Fe-55, Ni-63
  - gamma: Mn-54, Co-60, Ag-108m, Ag-110m, Sb-125, Cs-134, Ba-133, Eu-152, Eu-154, Eu-155

- fission products:
  - beta: Sr-90
  - gamma: Cs-137

- actinides:
  - alpha: isotopes of U, Pu, Am, Cm
  - beta: Pu-241
  - gamma: Am-241

develop a conceptual model of the site

- site diagram
  - known contamination
  - suspected contamination
  - potential reference areas
- classification
  - similar areas
  - current and past site characteristics
  - anticipated future use
- identify data gaps

professional judgement

where data:

- unavailable
- unreliable
- conflicting
- too costly or time consuming to obtain

based on:

- technical knowledge
- professional experience
- assumptions, algorithms and definitions

by experienced experts

- without potential conflict of interests
- with expertise in a required topic
- with objectiveness

valid for all surveys

decommissioning criteria

- regulatory agencies establish dose standards based on risk considerations
- "clearance levels" are calculated by analysis of various pathways and scenarios (direct radiation, ingestion, inhalation etc.)
- clearance levels are expressed as surface or mass specific activity (Bq/cm^2 or Bq/g) for each nuclide
- clearance levels may be general or site-specific
- additional conditions for implementing the clearance levels, e.g.:
    - statistical criteria
    - averaging area or mass
    - consideration of background

identify contaminants and establish clearance values

- identify potential radionuclide contaminants
- determine the relative ratios of nuclides (= “nuclide vector”)
- calculate the clearance levels for nuclide mixtures according to relative ratios of nuclides (e.g. Sr-90 to Cs-137)
  relative ratios of 2 nuclides = “scaling factors”
  relative ratios of a mixture = “nuclide vector”
- application of the “sum formula” or “unity rule”:

$$\frac{a_1}{CL_1} + \frac{a_2}{CL_2} + \ldots + \frac{a_n}{CL_n} \leq 1$$

where

a_i specific activity of nuclide i

CL_i clearance level of nuclide i

classification of areas by contamination potential

Class 1: known or potential radioactive contamination **above** clearance level

- former contamination control areas
- areas with remedial actions
- locations with known leaks or spills
- burial or disposal sites
- waste storage sites

Class 2: possible radioactive contamination **below** clearance level

- transport routes
- areas with handling of low concentrations of radionuclides
- perimeter of former contamination control areas

Class 3: **no** radioactive contamination expected

- buffer zones around class 1 or class 2 areas

select background reference areas

- some radionuclides may occur at significant levels as part of background in the media of interest (soil, building materials etc.)
- natural radionuclides
    - K-40
    - decay series of
        - U-238
        - U-235
        - Th-232
    - H-3
    - C-14
- artificial radionuclides (nuclear weapons fallout, Černobyl)
    - Cs-137
    - Sr-90

select background reference areas

- reference area should have similar characteristics as the survey unit:
    - physical
    - chemical
    - geological
    - radiological
    - biological
- selected from:
    - non-impacted areas
    - not influenced by handling of radioactive materials
- pay attention to variation of background values
    - different areas
    - different materials

identify survey units

- physical areas
- common radiological history
- consistent with exposure pathway modelling
- expect the same radiological characterisation

select instruments and survey techniques

depends on:

- radionuclides
    - nuclide specific method
    - gross measurement method
    - direct measurements
    - sampling
- detection sensitivities compared with cearance levels
    - detection limit = 10 – 50 % of clearance level
    - best available technique
- materials and surfaces
- environmental conditions
- time
- costs

site preparation

- consent for survey
  - owners
  - authority
  - other affected parties
- marking the boundaries
- physical characteristics
  - accessibility of the survey unit
  - removing of equipment and materials
  - accessibility to potentially contaminated surfaces
  - underground objects
    - pipes
    - tanks
    - possible contaminated material under buildings
  - excavated areas before backfilling

clearing to provide access

structures

- remove of covers, disassembly, produce openings
- provide means to reach some surfaces (cranes, ladders etc.)
- remove furnishings and equipment
- special attention to piping, drains, sewers, sumps, tanks
- unsealed porous materials (e.g. concrete, wood)
- remove wall and floor coverings (including paint, wax or other sealer)

clearing to provide access

land areas

- remove ground covers (e.g. concrete)
- clearing of brush and weeds
- depends on potential contamination
- pay attention to
    - underground structures
    - contamination of materials to be cleared
    - exposure of clearing personnel
    - potential ecological damage

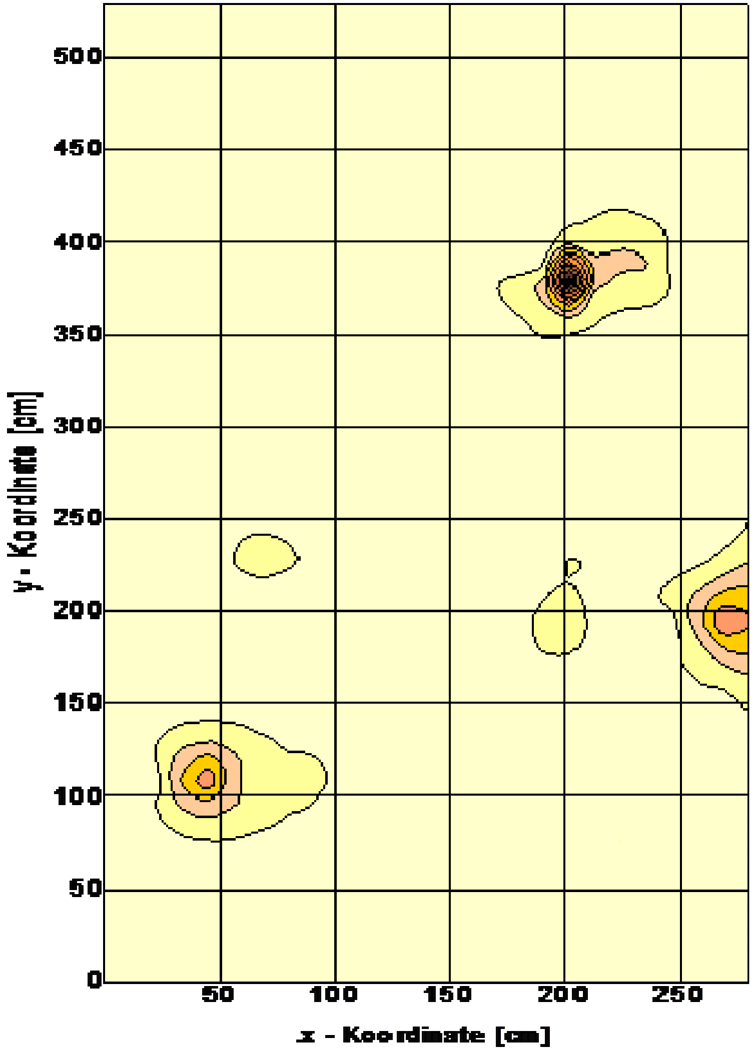
reference coordinate system

- provide a level of reproducibility consistent with objectives of the survey
- grid of intersecting lines
- referenced to a fixed site location or benchmark
- types e.g.
    - perpendicular pattern
    - 3-dimensional
    - polar
- intervals depend on objectives of the survey
    - not dictate the spacing or location of measurement or sampling points

reference coordinate system

- identification: e.g.
  - alphanumerical
  - distances to grid origin
  - altitude or level in buildings
  - GPS
- marking: e.g.
  - paint (lines or intersections)
  - wooden or metal stakes
- map or drawing of reference coordinate system

reference coordinate system



reference coordinate system

0	2	2	4	7	8	3	4	2	7
2	3	3	10	11	7	4	4	6	7
2	3	3	9	14	8	4	4	5	7
			10	30	8	8	4	5	7
			10	39	26	8	4	7	7
			10	90	80	8	4	7	8
			23	52	62	13	5	8	8
			26	31	47	14	5	8	8
			55	25	41	13	7	8	10
			41	28	29	14	11	8	10
			42	35	32	14	11	4	9
			43	35	28	15	13	7	10
			42	37	32	28	14	8	10
			67	51	47	33	11	9	10
			118	75	54	68	12	10	9
			197	117	107	78	14	10	9
			141	188	246	98	15	11	8
			149	343	623	167	47	12	9
			116	360	1003	198	53	13	12
						156	53	13	12
						105	37	12	13
						92	31	11	15
						70	32	11	12
						43	31	13	14
						34	29	17	14
						20	18	14	14
						8	17	13	6
						6	14	4	9
						6	8	4	7
						3	0	1	0
						3	0	-3	0

quality assurance

quality assurance project plan

- initiated at the start of a project
- objectives
  - reproducibility
  - accuracy
  - precision
- factors of bias, error and uncertainty
  - sample collection methods
  - handling and preparation of samples
  - homogenisation and aliquots of laboratory samples
  - field methods for scanning and direct measurements
  - laboratory analytical process

quality assurance

quality control measurements and analysis

•number depends on:

- degree of assurance (level of confidence)
- variability of survey unit
- complexity of investigation (duration, number of samples, methods, personnel, laboratories etc.)
- experience (personnel, methods, survey design etc.)
- level of radioactivity
- how close the clearance level is to detection limit
- potential uncertainty

qualification and experience of personnel

- planning
- measurements
- sampling (methods, materials)
- analysis
- quality assurance
- behaviour of radionuclides and compounds
- statistics
- operation of the facility
- location
- law and regulations

health and safety

- radiation protection
  - unexpected radioactivity
  - ingestion, inhalation particularly during sampling
- industrial hazards (similar to construction sites)
  - exposed electric installations
  - excavation
  - enclosed work space
  - hazardous atmosphere (tanks, underground buildings etc.)
  - working at heights

identify, eliminate, avoid or minimise potential safety hazards

documentation

- records about all measurements and sampling to assure reproducibility
- reference all locations to grid coordinates or fixed site features
- records about all deviations from the survey program
- records about all additional activities
- convert all measurement data into the same units as clearance levels prior to evaluation

objectives

- preliminary risk assessment
- site priorisation
- check and correct classification
- estimate variability
- identify non-impacted areas (appropriate for reference areas?)
- estimate level of effort for remediation
- information for planning of more detailed surveys
- may used as final status survey for Class 3 areas if detection sensitivities are in compliance with release criterion

methods

- surface scanning
- surface activity measurement (limited number)
- sampling (limited number to check the variability)
- background activity
- judgement measurements and sampling in areas likely to have accumulated radioactivity

evaluating results

- identify radionuclides
- identify locations and general extent of radioactivity
- estimate variability
- adjust clearance levels
- determine need for additional action (none, remediate, more surveys)
- prepare report

objectives

- determine the nature and extent of radioactive contamination
- evaluate remediation alternatives:
  - unrestricted use
  - restricted use
  - onsite disposal
  - off-site disposal
- input to pathway analysis, dose or risk assessment models for determination of site specific clearance levels (Bq/g, Bq/cm²)
- estimate occupational and public health and safety impacts during decommissioning
- re-evaluate the initial classification of survey units
- evaluate potential reference areas

objectives

- input to final status survey design
  - radionuclides
  - relative ratios of radionuclides (“nuclide vector”)
  - concentration ranges and variances
  - spatial distribution
- select instrumentation based on necessary detection limits

methods

- surface scanning
- measurements
  - one category may sufficient
    - surface activity
    - exposure rate
    - in-situ-gammaspectrometry
  - systematic and judgement
  - sensitivity appropriate to clearance levels
  - data may be used for final status survey
- sampling (surface and subsurface)
- combination of direct measurements and sampling
- investigate the change of nuclide ratios the depth
- lateral and vertical extent of contamination

methods

•site specific additional investigations

- surface water
- sediments
- ground water (also hazardous substances)
- air (e.g. radon)
- vegetation (in rare cases)

evaluating results

- confirm and add radionuclides
- evaluate nuclide ratios (“nuclide vector”)
- identify locations and extent for remediation
- determine need for additional measurements
- prepare report

objectives

- support remediation actions
  - location of residual radioactivity
  - extent of residual radioactivity
  - depth of residual radioactivity
- determine when ready for final status survey
- update estimates for planning final status survey

methods

- in real-time mode
- typical one simple radiological parameter
- direct measurements are preferred but it depends on radionuclides
- field laboratories and screening techniques may acceptable
- difficult to correlate scanning results with radionuclide concentration in soil
- measurement of excavated materials is possible to check the residual radioactivity in the soil in situ
- set investigation level for in-field decisions (< clearance level)
- for expediency and cost effectiveness no accurate data

or

- designed to meet the objectives of final status survey

evaluating results

- if measured parameter is above investigation level continue with remediation
- if measured parameter is below investigation level go to final status survey
- data for planning final status survey
- estimate variance, it may changed by remediation

objectives

- demonstrate compliance with criteria for release
    - for unrestricted use
    - for use with designated limitations
- demonstrate that all radiological parameters do not exceed clearance levels

survey design

- number and locations of measurements and sampling points
  - depends on:
    - variance
    - confidence level
    - nuclide in background or not
- select and implement survey techniques
- select instrumentation
- quality assurance measures
- discussion with regulatory agency concerning logistics for confirmatory or verification surveys (performed by regulatory agency or independent third party contracted by regulatory agency

methods

- scanning
  - Class 1: 100 %
  - Class 2: 10 – 100 % (systematically and judgement)
  - Class 3: judgement (areas with greatest potential of contamination)
- activity measurements
  - number according to statistical demands
- sampling and analysis
- values above investigation level
  - further investigation
  - reclassification
  - remediation
  - resurvey

methods

•application of statistical tests

- contaminant not in background: Sign test
- contaminant in background: Wilcoxon Rank Sum test
- define Type I decision error = “false positive” (α)
- define Type II decision error = “false negative” (β)

evaluating results

- comparison with clearance levels
- application of statistical tests
- if release criterion has been exceeded:
    - remediation
    - resurvey
    - other actions in agreement with regulatory agency

report

- stand alone document
- results of all measurements, sampling and analysis
- additional remediation actions
- all information for re-creation and evaluation
- should independently reviewed
- should be approved by designated person (or persons)
  - capable of evaluation all aspects
  - prior to release

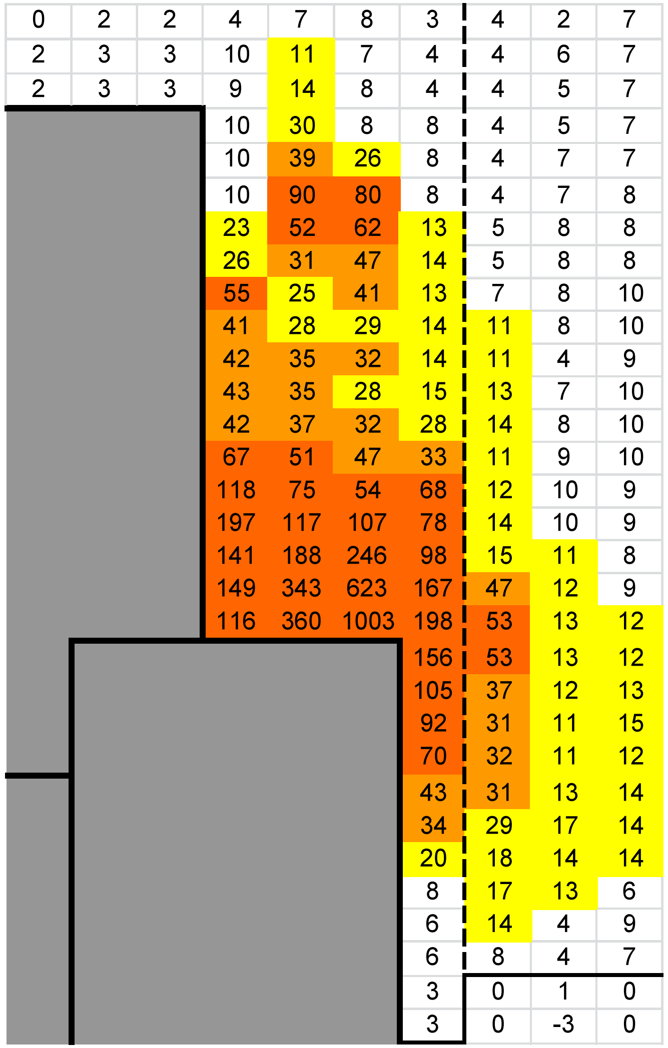
Measurement techniques

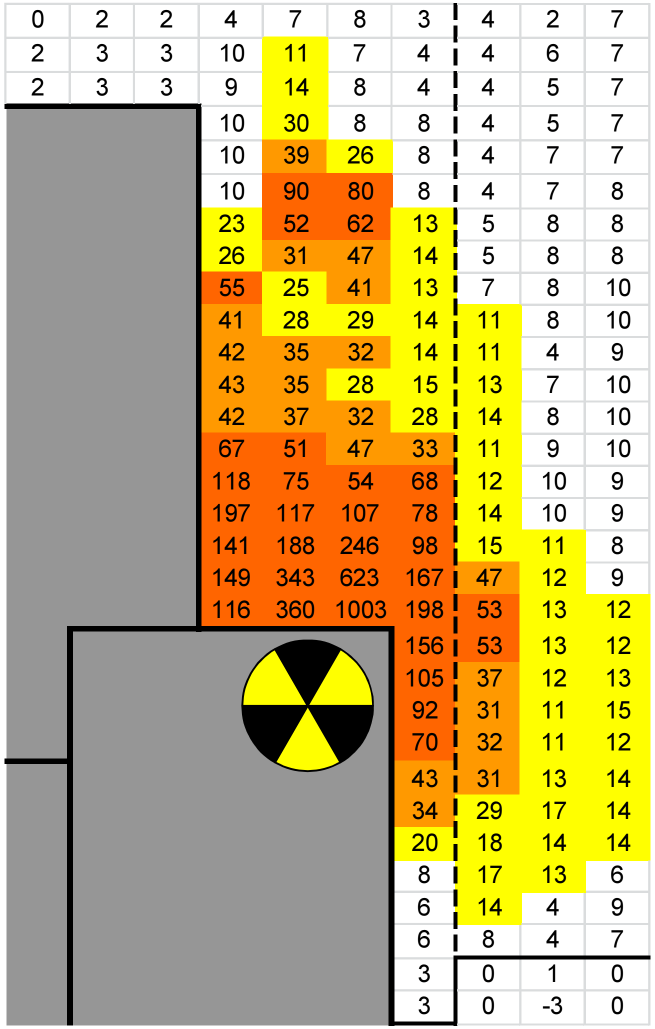
criteria

- nuclides, kind of radiation
- clearance level (investigation level)
- radiation background
- material
- surface
- distribution of radioactivity (homogeneity, depth)

selection of measurement technique

- problems with radiation background





non or badly detectable nuclides

- low energy pure beta emitters
  - H-3
  - Ni-63
- low energy photon emitters
  - Fe-55
- alpha emitters under an absorbing layer (dust, moisture, paint etc.)

selection of measurement technique

	surface contamination measurement	in-situ-gammaspectrometr y	laboratory analysis
parameter	gross alpha gross beta	gamma-nuclides	all nuclides
dimension	100 … 1000 cm²	1 … some 100 ²	sampling point, sampling area
time needed	very low	low - medium	high
results after	1 … 10 min	15 min … 12 h	1 d … some weeks
cost of equipment	low	medium - high	high
cost of measurement	low	medium	medium - high

quality indicators

- accuracy (bias)
- precision
- selectivity
- comparability

surface activity

- alpha and beta
  - thin window gas flow proportional counter
  - scintillation counter
- gamma:
  - NaI
  - organic scintillation counter

remediation control

large area detector

multiple measurements

surface contamination measurement

electric driven shielded measuring instrument

surface contamination measurement

dynamic measurement

total gamma measurement

- scintillation detectors
    - organic scintillation counter

clearance measuring station

radiation detectors

- gas filled detectors (Geiger-Müller-counter)
- scintillation detectors
  - NaI(Tl)
  - ZnS(Ag)
  - CdTe
  - CsI(Tl)

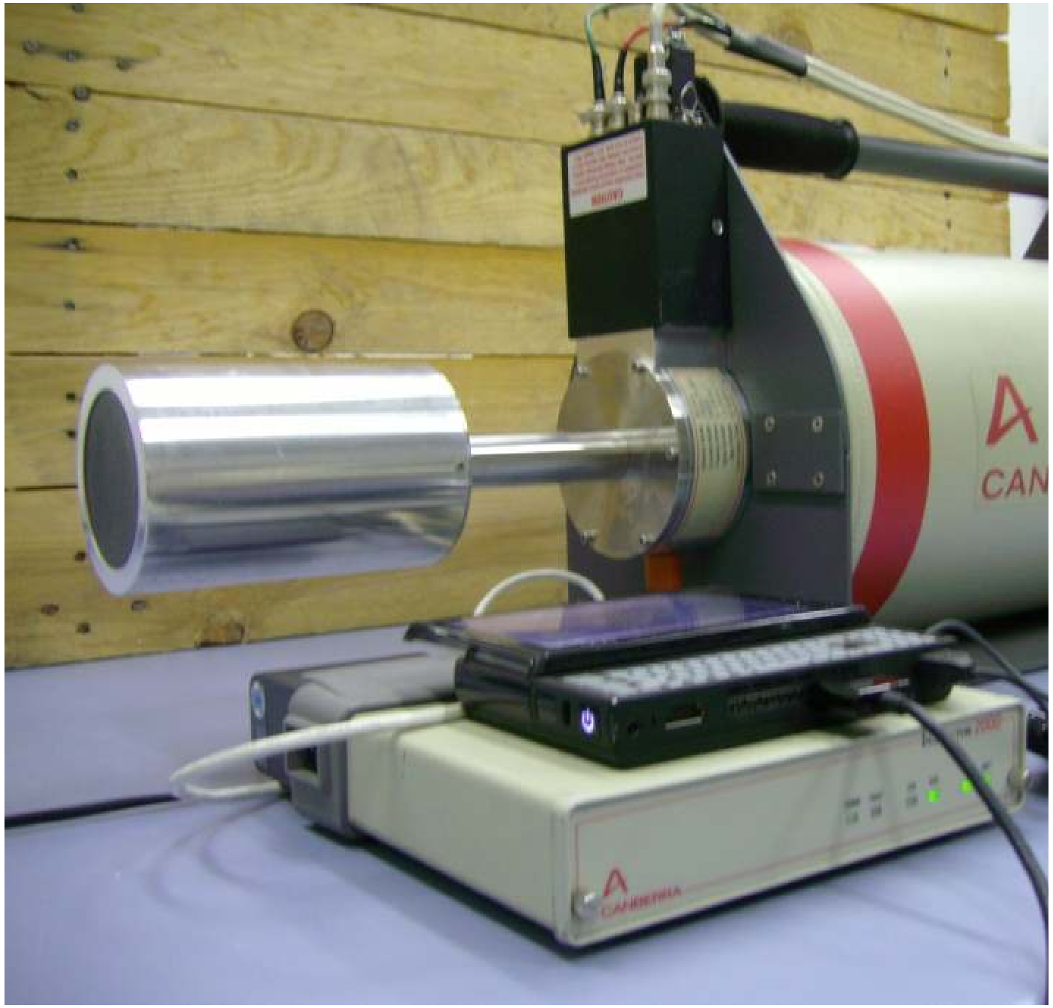
radiation detectors
gamma logging

in-situ-gamma spectrometry

- detector type
  - coaxial
  - planar
- window
  - material
  - thickness
- cooling
  - liquid nitrogen
  - electrical

NaI-detector

HPGe-detector



- shielding (collimator 180°)

- shielding (collimator 90°)

in-situ-gamma spectrometry

in-situ-gamma spectrometry

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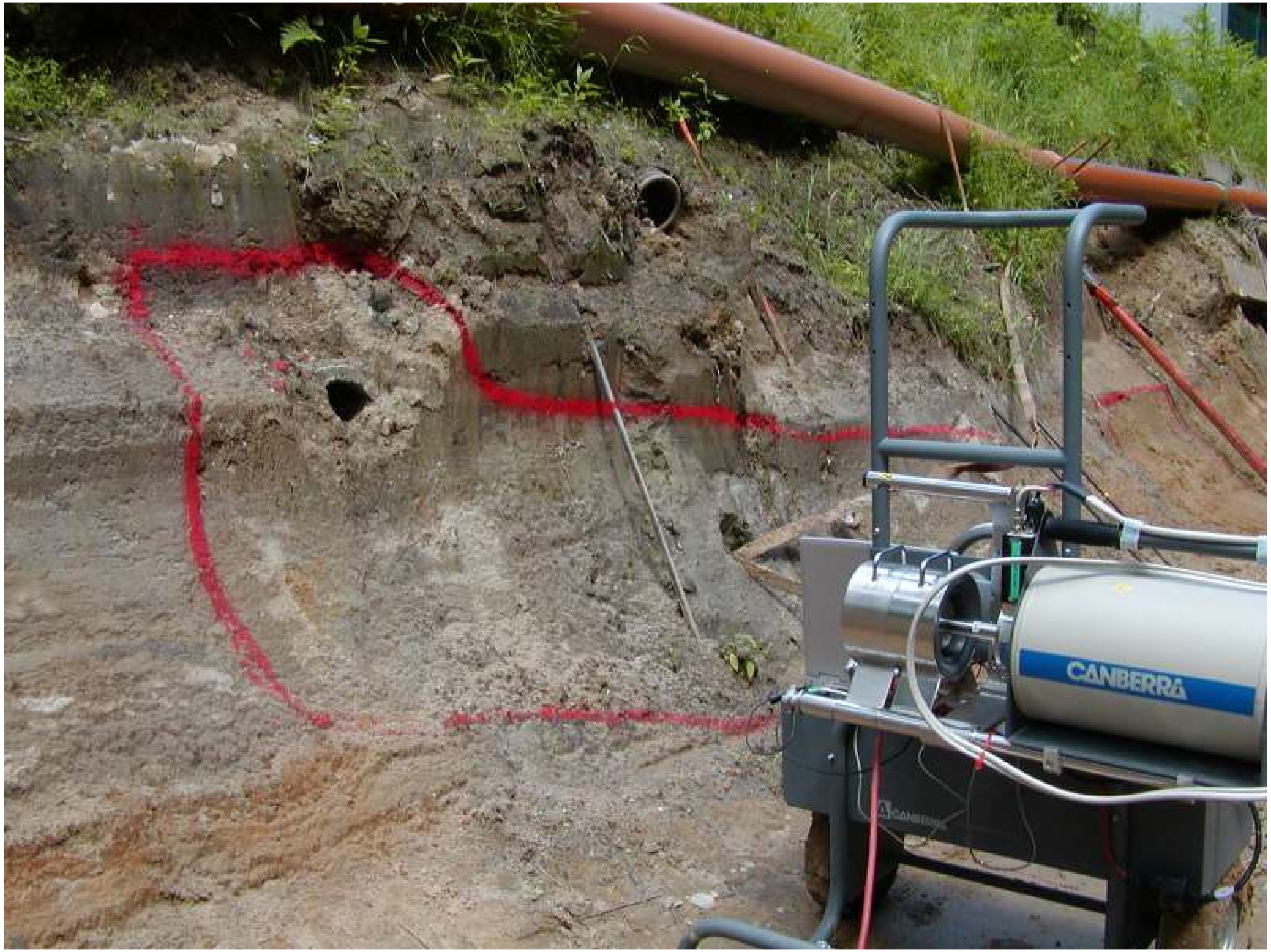
in-situ-gamma spectrometry

in-situ-gamma spectrometry



in-situ-gamma spectrometry

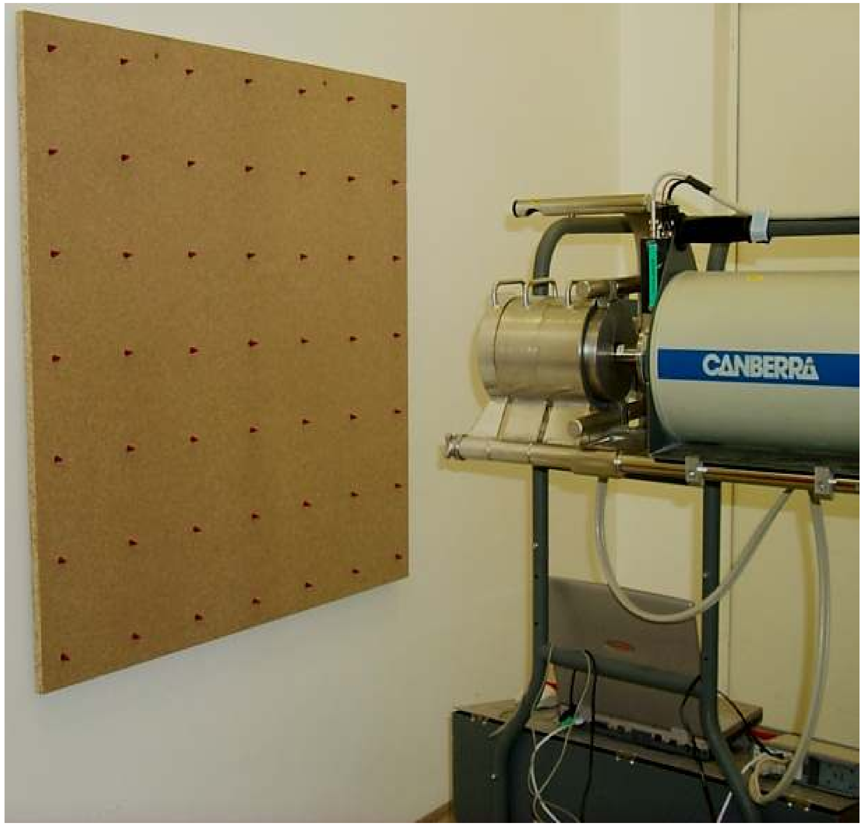
calibration

- differences between calibration and routine use
  - geometry
  - uniformity of contamination
  - surface characteristics (e.g. roughness)
  - overlaying material (dust, moisture, paint etc.)
- correction in sometimes possible by factors
- $\varepsilon_{total} = \varepsilon_{detector} \cdot \varepsilon_{source}$
  - different nuclides
  - source characteristics
- regularly response checks
- uncertainty
  - conservative calibration
  - value + 2 SD < clearance level (confidence level 95 %)

calibration

in-situ-gamma spectrometry

concrete calibration object



area calibration object

calibration tube

proficency test

in-situ-gamma spectrometry intercomparison

selecting criteria or service providers

1. validated SOP, appropriate instrumentation, trained personal
2. experience in the same or similar data collection activities
3. satisfactory performance evaluation
   - QA audits, QC measurement, traceability to standards
4. adequate capacity to perform the work within the timeframe
   - number of personnel and calibrated equipment
5. internal quality control review
   - independent from data generators
6. adequate protocols for method performance documentation, sample tracking and documentation of results

selecting criteria or service providers

- QM-system
- accreditation according to ISO/IEC 17025

"General requirements for the competence of testing and calibration laboratories"

Sampling and Analysis

selection of sampling points

- depends on objectives
    - overview
    - inventory
    - radiological characterisation (“nuclide vector”)

- possibilities:
    - grid
    - greatest potential of contamination
    - maxima of previous direct measurements
    - stochastic
    - combination

representative samples

- good selection of sample point
- avoid cross contamination
- without foreign material (roots, glass, meta, concrete etc.)
- appropriate sampling technique
- appropriate sample size
  - homogeneity
  - grain size
  - amount for analyses
  - soil typical 100 g … some kg
- sample container (polyethylene, glass)
- preservation of sample normally not necessary

- sampling methods
  - surface samples
    - scraping
    - chiselling
    - wiping
  - material samples
    - direct collection
    - drilling cores
    - drill dust
    - chiselling
    - “stocker”-samples

sampling

- scraping

sampling

sampling

drilling

sampling

drilling

depth profile

drilling, drill dust collection

sampling

core drilling

core drilling

sampling

core piling

sample tracking – “chain-of-custody”

•sampling report (incl. photo, sketch, map)
•labelling (system of sample numbers)
•packing
•sample list
•transport conditions
•storage in laboratory
•aliquoting

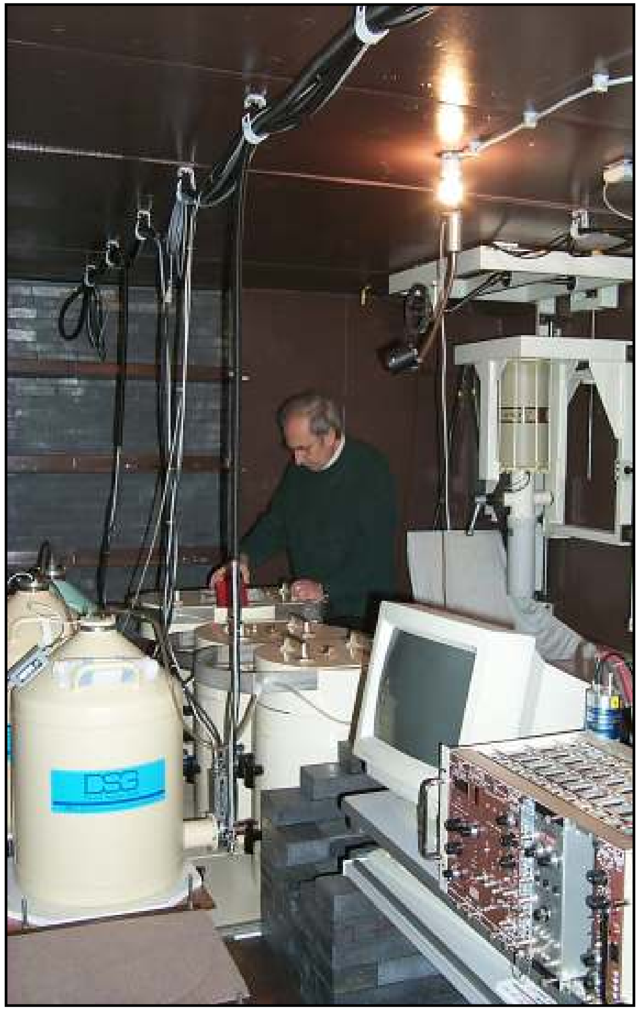
sample reparation in the laboratory

- drying
- grinding, milling
- combustion
- aliqouting
- dissolution
- radiochemical separation
- preparation for measurement

analytical methods

- gamma spectrometry:
    - Co-60, Cs-137, Eu-152, Am-241, …
    - K-40, decay series of U-238, U-235 and Th-232
- liquid scintillation counting (LSC):
    - after radiochemical separation
    - H-3, C-14, Cl-36, Ca-41, Fe-55, Ni-63, Sr-90, Pu-241
- alpha spectrometry:
    - after radiochemical separation
    - Th-232, U-234, U-235, U-238, Pu-238, Pu-239/240, Am-241, Cm-242, Cm-243/244
- inductively coupled mass spectrometry (ICP-MS):
    - Th-232, U-234, U-235, U-238
- (alpha total)
- (beta total)

gamma spectrometry



mass spectrometry with inductively coupled plasma (ICP-MS)
VG Elemental „AXIOM“

analysis

radiochemical separation

verification and validation of data

- all data complete
- meet the results the required detection limits
- questionable results
    - check records
    - check QA documentation
    - repeat analysis
    - repeat sampling

Determination of “nuclide vectors”

for clearance measurements it is possible to refer to an easy measurable nuclide if:

- nuclides in a mixture are in a fixed ratio to each other and
- the ratio is known

nuclide vector:
percentage of nuclides in a nuclide mixture

for clearance the nuclide vector has to be **representative** and **sufficiently conservative**

- **Representativeness** is not to secure by special features of samples.
- A sample is representative when it is taken by a selection method that is both **accurate and reproducible**.

- Representativeness is not to achieve absolutely with reasonable effort.
- It can be achieved only to a previosly determined **confidence level**.

compilation and validation of data

- delimit regions with expected homogeneous nuclide vectors
- compilation of available data for nuclide composition
  - data from documentation during operation
  - analytical results of samples
    - gamma spectrometry
    - radiochemical analysis
  - results of in-situ-gamma spectrometry
  - model calculations of activation and burn-up
- check of data
  - complete?
  - plausible?
  - up-to-date? (decay correction if necessary)

calculation of nuclide vectors for all samples

- nuclides below detection limits
  - will be not considered
    - if nuclide is not relevant for the object
    - if detection limit is low enough
  - for extremely conservative treatment
    - detection limits are considered like real values if the nuclide is relevant for the object.
    - lead to a more or less **overestimation** of this nuclides and may result in **false conclusions**!

!

sample	percentage in nuclide vector [%]			
	Co-60	Cs-137+	Sb-125+	Am-241
before decontamination	90,7	9,3	0,009	0,001
after 1st decontamination	80,8	8,2	8,0	3,0
after 2nd decontamination	50,1	7,0	28,2	14,7

sample	specific activity [Bq/g]			
	Co-60	Cs-137+	Sb-125+	Am-241
before decontamination	534,0000	55,0000	< 0,0510	< 0,0055
after 1st decontamination	0,0138	0,0014	< 0,0014	< 0,0005
after 2nd decontamination	0,0018	0,0003	< 0,0010	< 0,0005

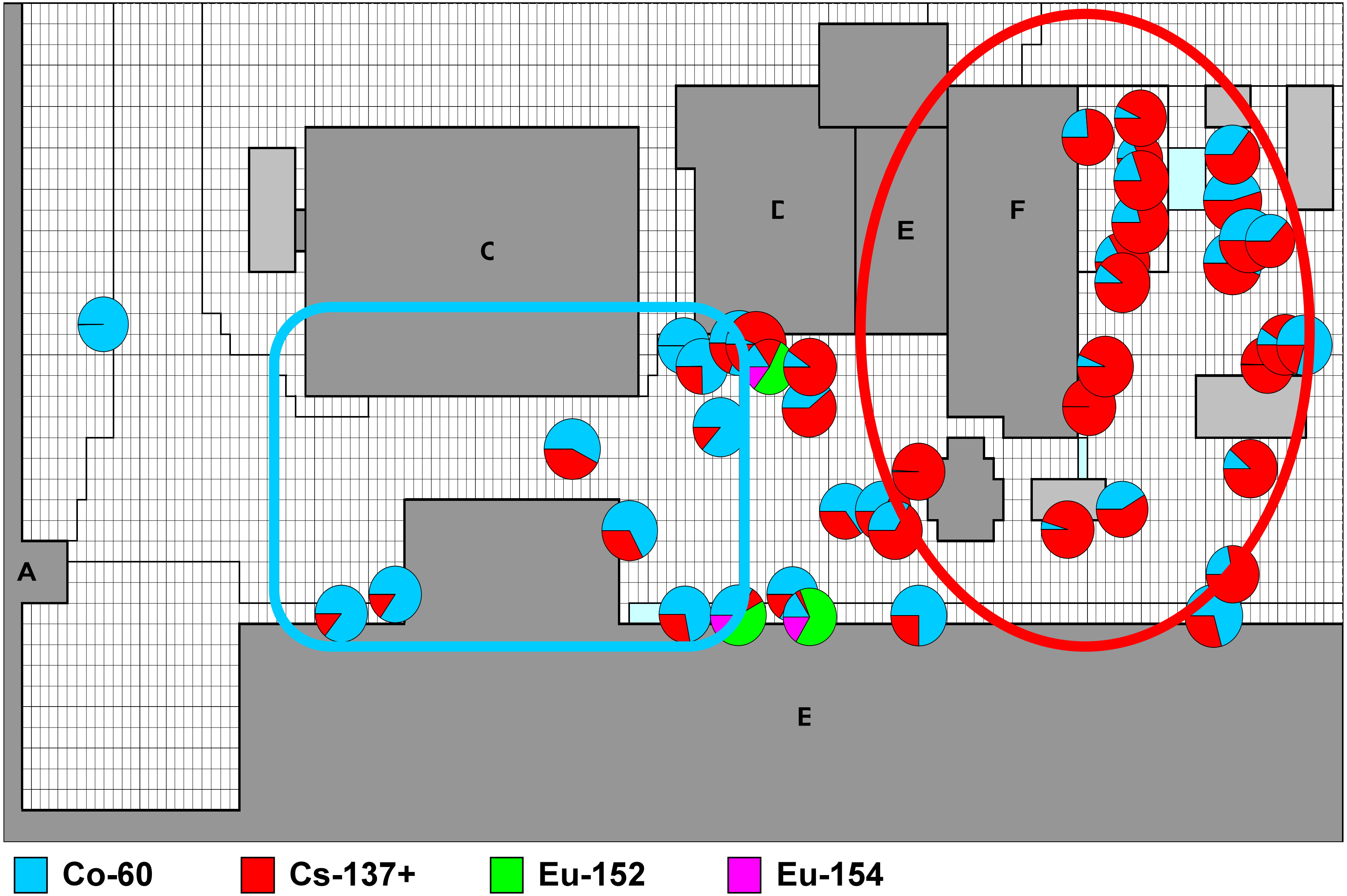
sample	percentage in nuclide vector [%]			
	Co-60	Cs-137+	Sb-125+	Am-241
before decontamination	90,7	9,3	0,0	0,0
after 1st decontamination	90,8	9,2	0,0	0,0
after 2nd decontamination	91,0	9,0	0,0	0,0

test of hypothesis „homogeneity of delimited regions“

in case of very heterogeneous contaminations

- division in homogeneous subregions
- use of covering nuclide vectors is sometimes possible, but extremely conservative
- no nuclide vector possible, particularly if no uniform key nuclide exists
- check, if the residual contamination will be homogeneous after decontamination

nuclide percentage near an isotope production facility (in-situ-gamma spectrometry)



Calculation procedures for nuclide vectors:

- calculation by averaging
- calculation of covering nuclide vectors
- calculation on statistical basis

- calculation by **averaging**

sample	nuclide percentage [%]							
	Fe-55	Ni-63	Co-60	Sr-90+	Cs-137+	Pu-238	Pu-239/240	Am-241
1	12	13	54	5	6	4,0	4,0	2,0
2	20	8	42	11	15	1,9	1,1	1,0
3	9	6	48	21	12	1,7	1,2	1,1
4	10	6	47	20	12	2,2	1,3	1,5
5	10	17	42	12	9	6,0	2,0	2,0
6	11	10	46	15	11	2,8	1,2	3,0
average	12,0	10,0	46,5	14,0	10,8	3,1	1,8	1,8

calculation procedures

- calculation by averaging
  - nuclide vectors are **not conservative**
    - violation of the clearance limits may occur dependent on total activity
  - correction:
    - limitation by **threshold values** for the key nuclide depending on used clearance option and measuring procedure

- calculation of **covering nuclide vectors**
  - selection of the highest percentages for non-key nuclides
  - rest for the key-nuclide

sample	nuclide percentage [%]							
	Fe-55	Ni-63	Co-60	Sr-90+	Cs-137+	Pu-238	Pu-239/240	Am-241
1	12	13	54	5	6	4,0	4,0	2,0
2	20	8	42	11	15	1,9	1,1	1,0
3	9	6	48	21	12	1,7	1,2	1,1
4	10	6	47	20	12	2,2	1,3	1,5
5	10	17	42	12	9	6,0	2,0	2,0
6	11	10	46	15	11	2,8	1,2	3,0
average	12,0	10,0	46,5	14,0	10,8	3,1	1,8	1,8
maximum	20	17		21	15	6,0	4,0	3,0
rest			14					

Σ 86

calculation procedures

- covering nuclide vectors
  - substantial **overestimation of non-gamma nuclides**
  - reduction of conservatism
    - using the ratio to the key nuclide (expansion factor)
    - grouping of nuclides with similar clearance values, e.g. alpha nuclides, Fe-55/Ni-63
    - formation of sub nuclide vectors e.g.:
      - activation products (Co-60)
      - fission products (Cs-137)
      - transuranium nuclides (Am-241)

- correction of covering nuclide vector by **grouping**

sample	nuclide percentage [%]					
	Fe-55 + Ni-63	Co-60	Sr-90+	Cs-137+	Pu-isotopes + Am-241	
1	25	54	5	6	10,0	
2	28	42	11	15	4,0	
3	15	48	21	12	4,0	
4	16	47	20	12	5,0	
5	27	42	12	9	10,0	
6	21	46	15	11	7,0	
average	22	47	14	11	6,7	
maximum	28		21	15	10	Σ 74
rest		26				

- covering nuclide vector using the ratios to key nuclide (**scaling factors**)

sample	ratio to key nuclide Co-60 (= 1)								
	Fe-55	Ni-63	Co-60	Sr-90+	Cs-137+	Pu-238	Pu-239/240	Am-241	sum
1	0,222	0,241	1,000	0,093	0,111	0,074	0,074	0,037	
2	0,476	0,190	1,000	0,262	0,357	0,045	0,026	0,024	
3	0,188	0,125	1,000	0,438	0,250	0,035	0,025	0,023	
4	0,213	0,128	1,000	0,426	0,255	0,047	0,028	0,032	
5	0,238	0,405	1,000	0,286	0,214	0,143	0,048	0,048	
6	0,239	0,217	1,000	0,326	0,239	0,061	0,026	0,065	
maximum	0,476	0,405	1,000	0,438	0,357	0,143	0,074	0,065	2,96

nuclide vector	16,1	13,7	33,8	14,8	12,1	4,8	2,5	2,2

- calculation on **statistical basis**
  - statistical aspects
    - consideration of measurement uncertainty
    - variability of samples of one region
  - confidence level

    (95 % according to German regulations)
  - optimisation for 3 goals
    - conservative in reference to **mass-related clearance values**
    - conservative in reference to **area-related clearance values**
    - conservative in reference to **scaling factors**
  - commercial software (e.g. „ReFOM – Reststoff-Freigabe-Optimierungs-Modul“ by Brenk Systemplanung)

    or with Excel-sheets

- calculation on statistical basis
  - **homogeneity test** of nuclide vectors of all samples from a region (normal- or log-normal distribution)
  - vary the nuclide percentages according to **„one-sigma-concept“**, that means in a span

$$(\bar{x} - \sigma) \leq x \leq (\bar{x} + \sigma)$$

- vary to attain the following **sub-goals**
  - $\sum_i \frac{a_i}{R_i} = Maximum$
  - $\sum_i \frac{a_i}{O_i} = Maximum$
  - $\sum_i v_{\alpha+\beta,i} = Maximum$

a_i – specific activity of nuclide i

R_i – mass-related clearance value of nuclide i

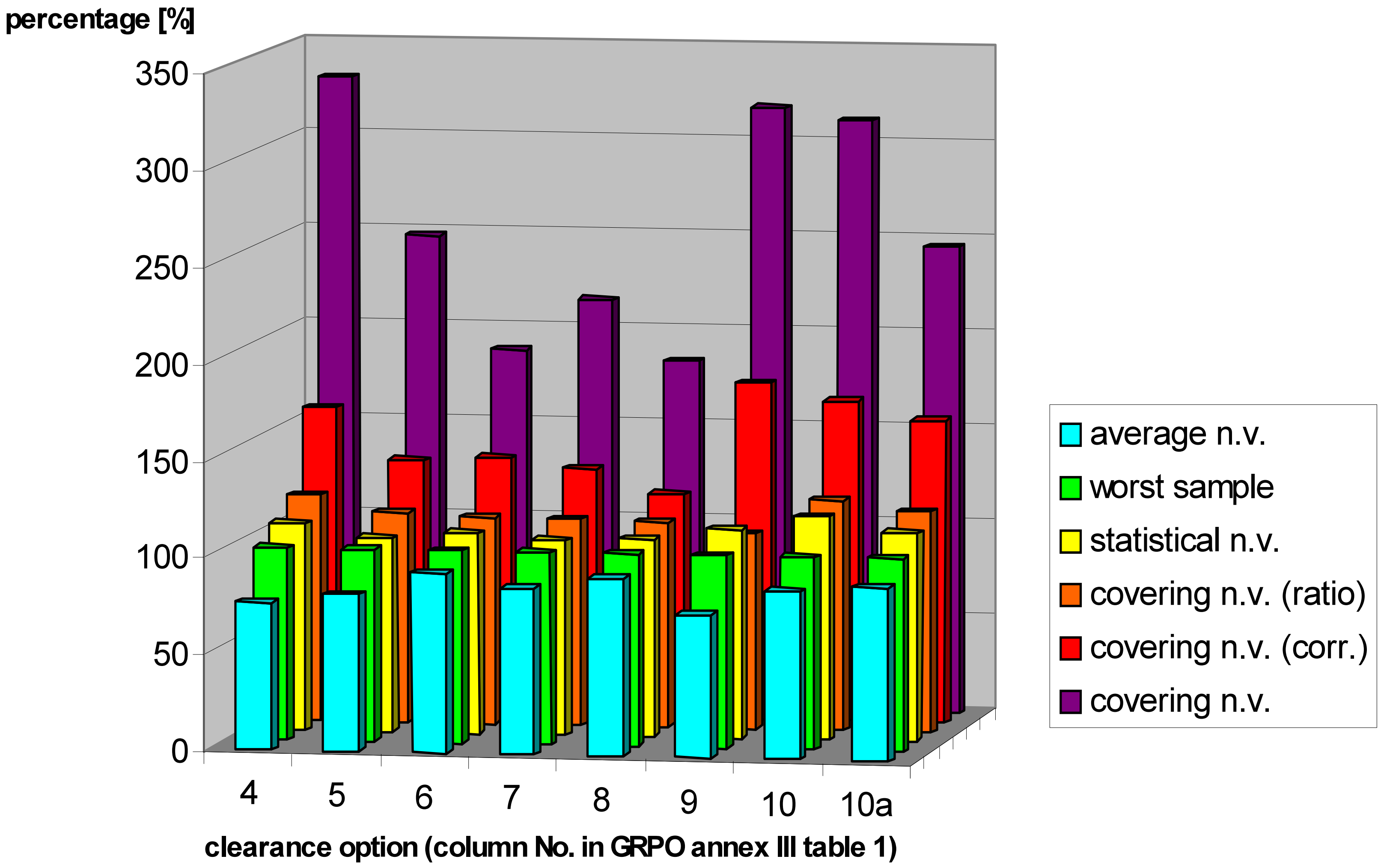
O_i – area-related clearance value of nuclide i

$v_{\alpha+\beta,i}$ – percentage of alpha- or beta-emitting nuclide i (without well measurable gamma rays)

- these sub-goals are **not** to attain simultaneously at the best

  → need to **optimise**
- **level of conservatism** will be known
- If the level of conservatism is not sufficient, it is possible to set **threshold values** for the clearance measurements.

percentages in relation to clearance values (example)
(worst sample = 100 %)



Comparison of calculation procedures for nuclide vectors

feature	calculation procedure		
	averaging	statistical basis	covering nucl. vect.
effort	low	high	middle
measurement uncertainty	difficult to include	included	difficult to include
statistical distribution of data	beneficial	essential	not necessary
consideration of mass- and area-related clearance values	not necessary	together	separate
representative	yes	(yes)	no
conservative	no	moderate	high
correction possibilities	thresholds for clearance measurements	(thresholds for clearance measurements)	grouping of nuclides, use of nuclide ratios
clearance options	all	prior selected	multiple possible
measurement procedures	all	prior selected	prior selected
„fictitious activity“ in balance	no	low - middle	high

label nuclide vectors clearly

- kind of nuclide vector (e.g. averaging, covering)
- area of application (material, territory)
- reference date, when indicated validity period
- selected clearance options

Update

- check the **demand** for update
  - decay of short living nuclides
  - after decontamination
  - new data of clearance measurements
- update according the **same rules** like generation
- invalidate the previous nuclide vector

literature

MARSSIM: Multi-Agency Radiation Survey and Site Investigation Manual
http://www.epa.gov/rpdweb00/marssim/index.html

Thank you for attention!