Field gamma-spectrometry measurements near a nuclear power plant and on Roskilde Fjord

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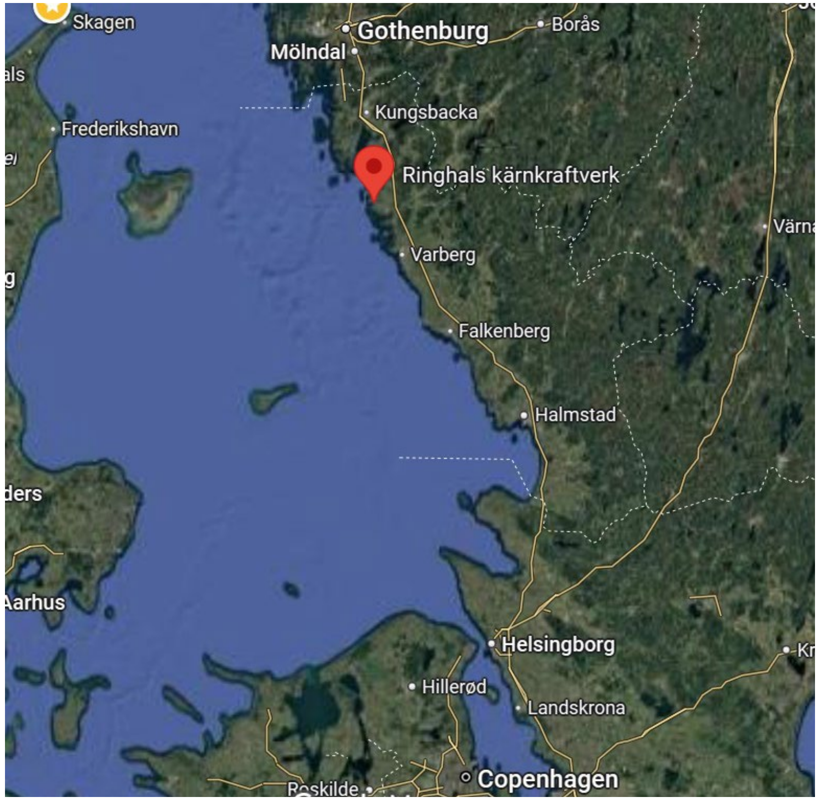
Background

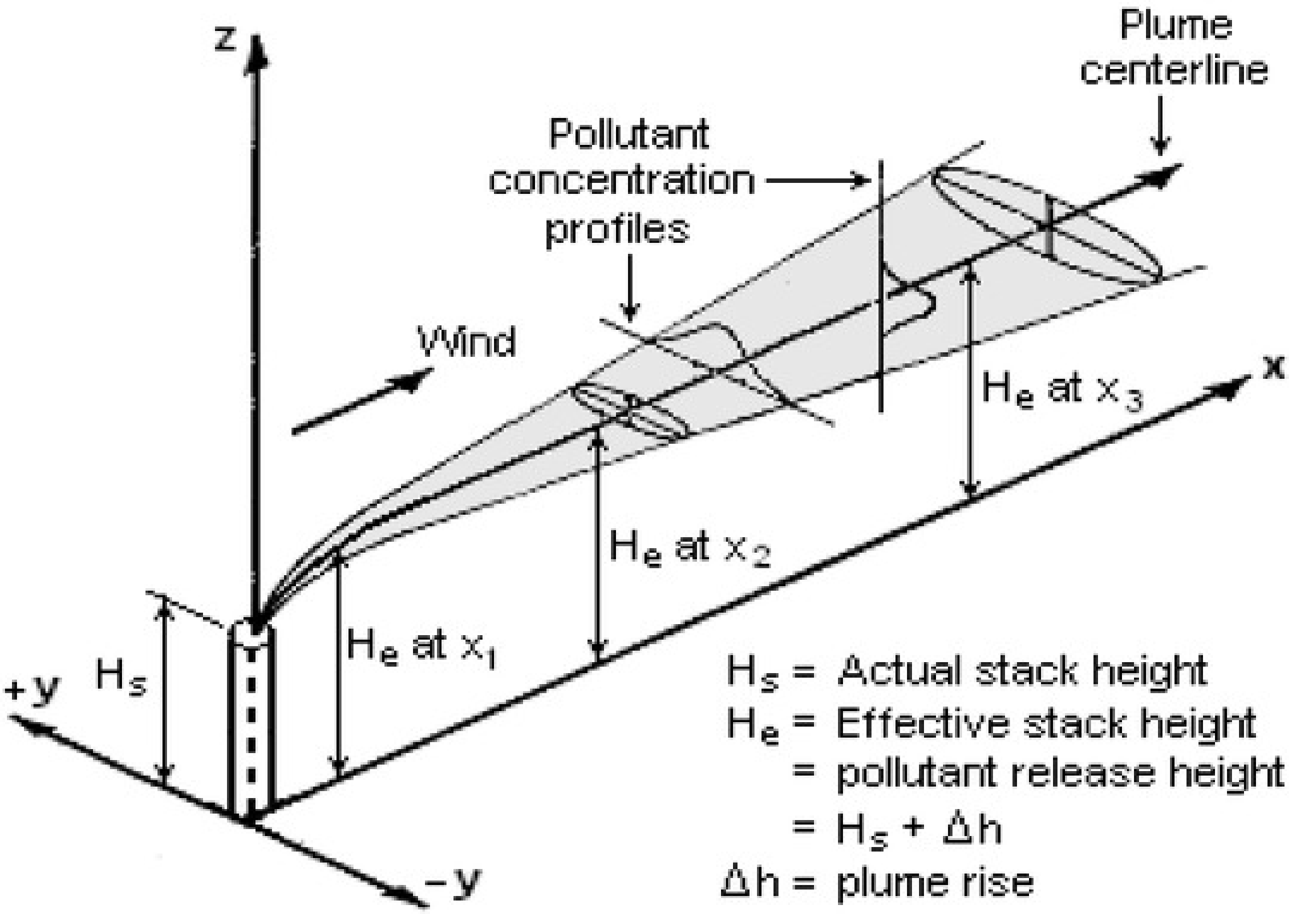
- 1975, Reactor Safety Study (WASH-1400, Rasmussen Report by US Nuclear Regulatory Commission), a comprehensive work on reactor safety and its methodologies, using Probabilistic Risk Assessment
- Swedish nuclear power plant Barsebäck, operations start in 1975 and 1977
- 1979 Three Mile Island nuclear power plant accident at Harrisburg in Pennsylvania
- 1985, the Danish government rules nuclear energy out of public planning after strong societal opposition to nuclear energy in the 1970s-80s

Atmospheric dispersion experiments at the Ringhals nuclear power plant, May 1981

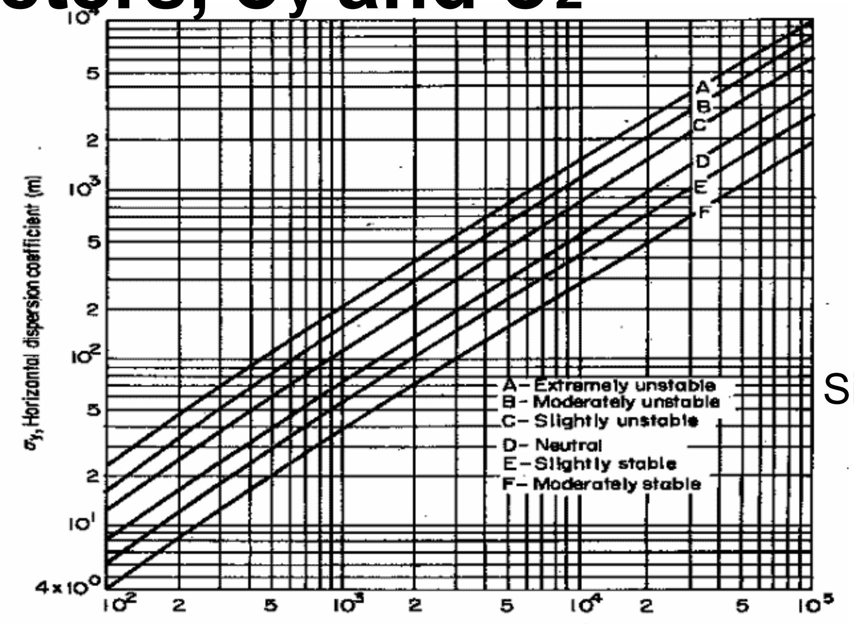


- The Ringhals nuclear power plant is situated on the Swedish west coast 50 km south of Gothenburg. The radioactive noble gases used for the experiments were routine emissions from unit 1 (BWR).
- The aim of the experiments was to obtain short-term observations of concentrations and gamma-ray exposures from stack effluents and compare these results with corresponding values calculated with computer models
- Two tracers, sulphur hexafluoride (SF_6) and radioactive noble gases were released from a 110-m stack and detected downwind at ground level at distances of 3-4 km. Calculations were made with two Gaussian plume models PLUCON (Risø National Laboratory) and UNIDOSE (Studsvik Energiteknik AB).
- The work was supported by the Nuclear Safety Board of the Swedish Utilities and by the Danish Utility Association, Elsam

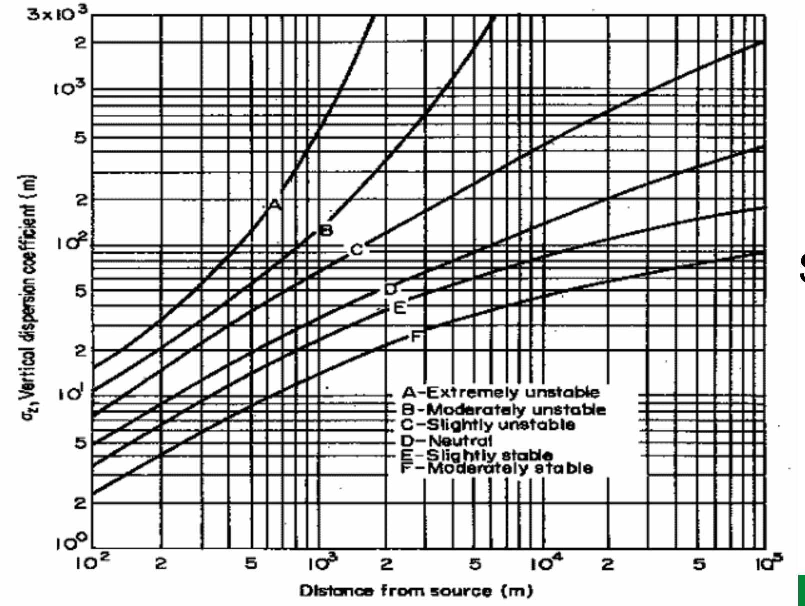
Gaussian plume model and parameters, σ_y and σ_z



Equation $$C(x,y,0) = \frac{Q}{U}\frac{1}{\pi\sigma_y\sigma_z} e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} e^{\left(\frac{-H^2}{2\sigma_z^2}\right)}$$



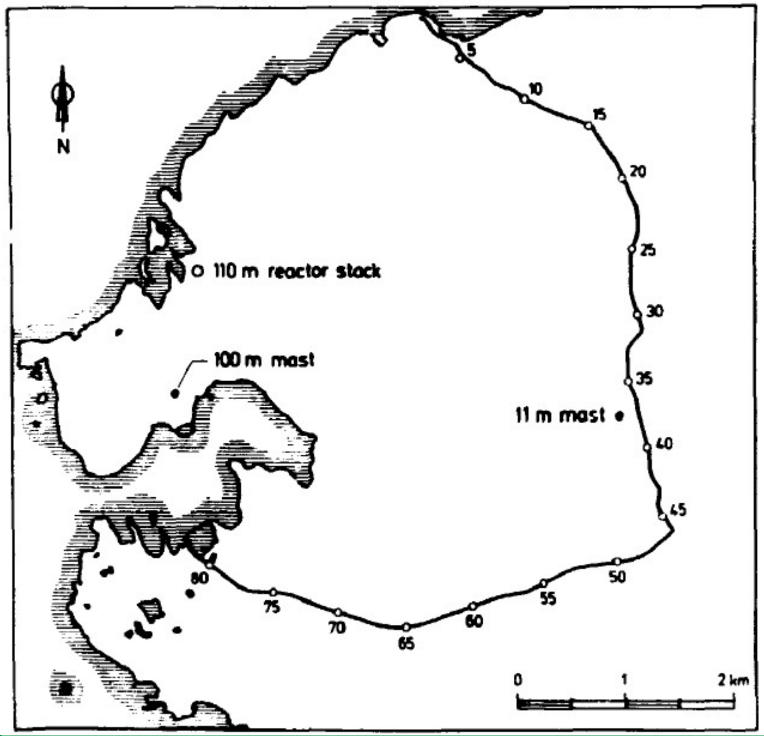
Sigma y



Sigma z

Meteorological data

- The experiments were based on a good meteorological forecast and required one hour for the setting up of the sampling network. Via radio control one-hour sampling of SF_6-concentrations and gamma radiation was synchronized for all positions.
- An 11-m meteorological mast was set up in a homogeneous flow field east of the reactor stack. The mast gave information at different heights on wind speed, wind direction, and temperature. During each experiment, a radiosonde was launched from here yielding information on the vertical structure of temperature and humidity in the atmosphere.
- During experiments I, III and IV, the meteorological conditions were near neutral corresponding to Pasquill category D with wind speeds of 8-14 m/s. Experiment II was made under stable conditions, Pasquill category E, with a wind speed of 3.5 m/s.



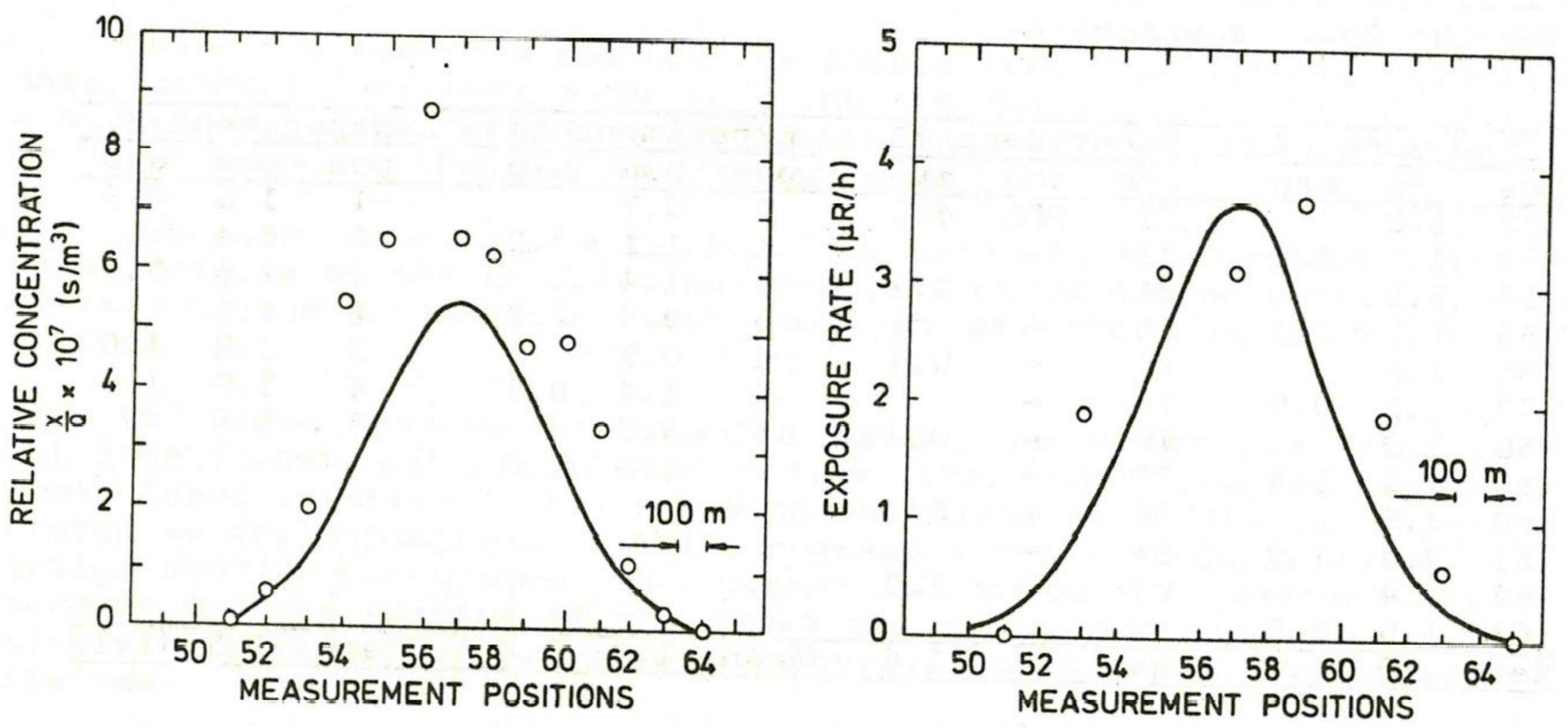
Measurement equipment

- The tracer SF_6 was injected to the stack at a constant rate. Prior to an experiment the automatic sampling units were transported to positions marked out in advance and distributed according to the actual wind direction. The distance between the sampling units was typically 150 m, 25 units were available. Air samples in bags were collected immediately after each experiment and later analyzed on site for their content of SF_6 by use of gas chromatography.
- The noble gases emitted from the stack were monitored continuously at the power station. The radiation from the plume was detected with 11 GM-counters, 3 ionization chambers, and 3 mobile Ge spectrometer systems. These instruments were intercalibrated prior to the experiments. The GM-counters and the ionization chambers gave information on exposure rates, whereas the gamma spectrometers gave information on unscattered gamma radiation, which permitted identification and quantification of the individual radionuclides.

Effective stack height, wind speed and stability

Experiment	Effective stack height (m)	Wind speed (m/s)	Pasquill stability class
I, May 23 14:31–15:31	139	8.5	D
II, May 23-24 23:24–00:24	199	3.5	E
III, May 25 11:33–12:33	147	8.0	D
IV, May 28 12:40–13:40	119	13.6	D

Crosswind profiles of relative concentrations and gamma exposure rates from experiment I



Measured o

Calculated -

Ratios of measured-to-calculated values of concentrations and gamma exposure rates in crosswind positions for the four experiments

Experiment I			Experiment II			Experiment III			Experiment IV		
pos	con	exp	pos	con	exp	pos	con	exp	pos	con	exp
52	1.0		72	BDL	4.5	0	0.7		-1	1.6	0.9
53	1.5	2.1	73	-		1	1.1	0.2	0	1.4	
54	2.2		74	-	2.1	2	1.4		1	1.4	0.9
55	1.7	1.2	75	-		3	0.9	0.2	2	1.3	
56	1.8		76	-	0.4	4	0.9		3	1.8	1.0
57	1.2	0.9	77	-		5	1.4	0.2	4	2.0	1.5
58	1.2		78	-	0.4	6	3.0		5	1.0	
59	1.2	1.4	79	-		7	1.0	1.0			
60	1.9		80	-	0.7						
61	2.3	1.9	81	-							
62	1.4		82	-	1.3						
63	1.0	2.0									
Mean	1.5	1.6	Mean		1.6	Mean	1.3	0.4	Mean	1.5	1.1

BDL below detection limit

Radioactive noble gases and daughters identified

Isotope	Halflife
Kr-85m	4.48 h
Kr-87	1.27 h
Kr-88	2.84 h
Rb-88	17.8 min
Xe-133	5.24 d
Xe-135	9.14 h
Xe-135m	15.3 min
Xe-138	14.1 min
Cs-138	33.4 min

Gamma spectrum from experiment I, pos. 55

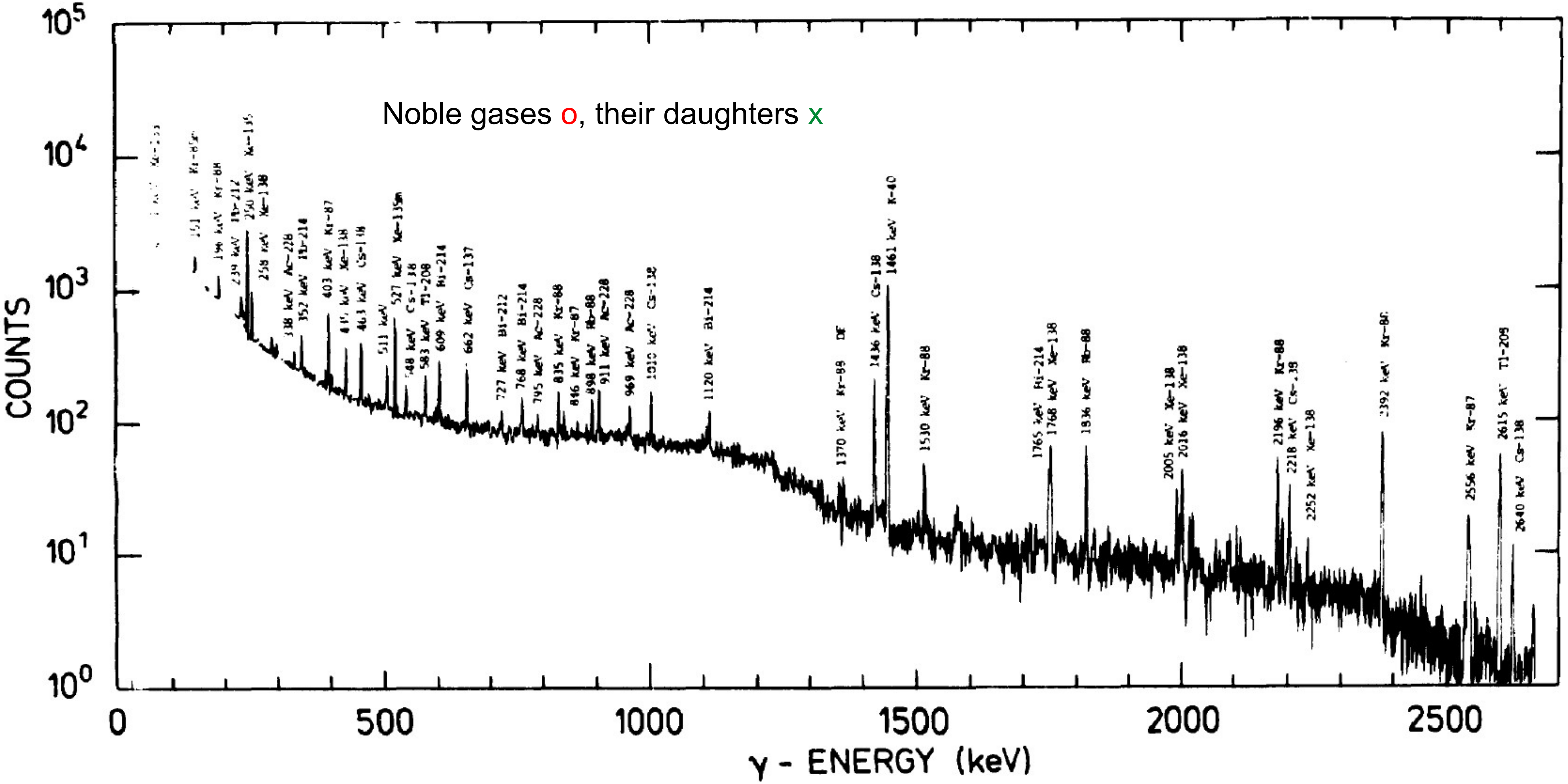


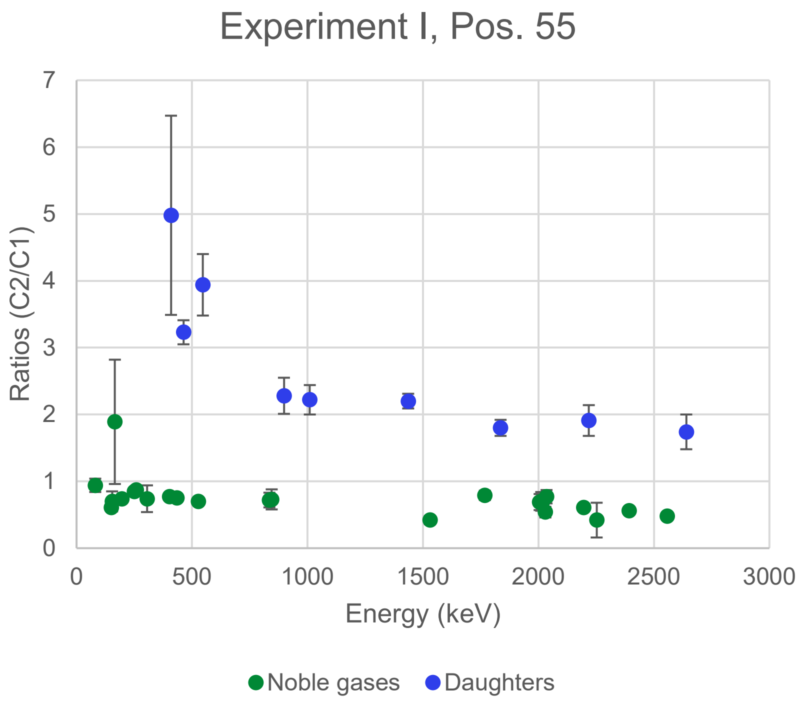
Fig.12. Gamma spectrum measured in experiment I at position 55.

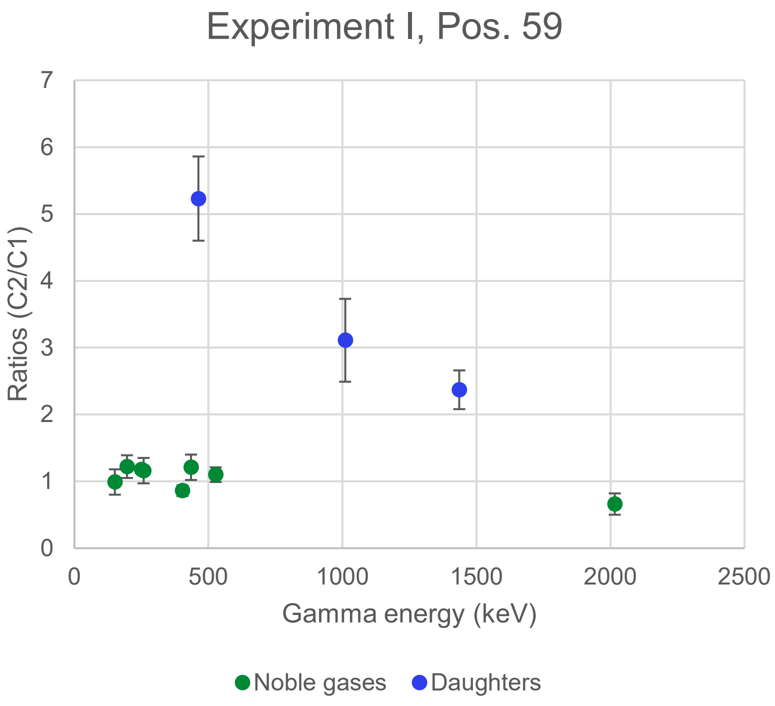
Dry deposition of noble gas daughters

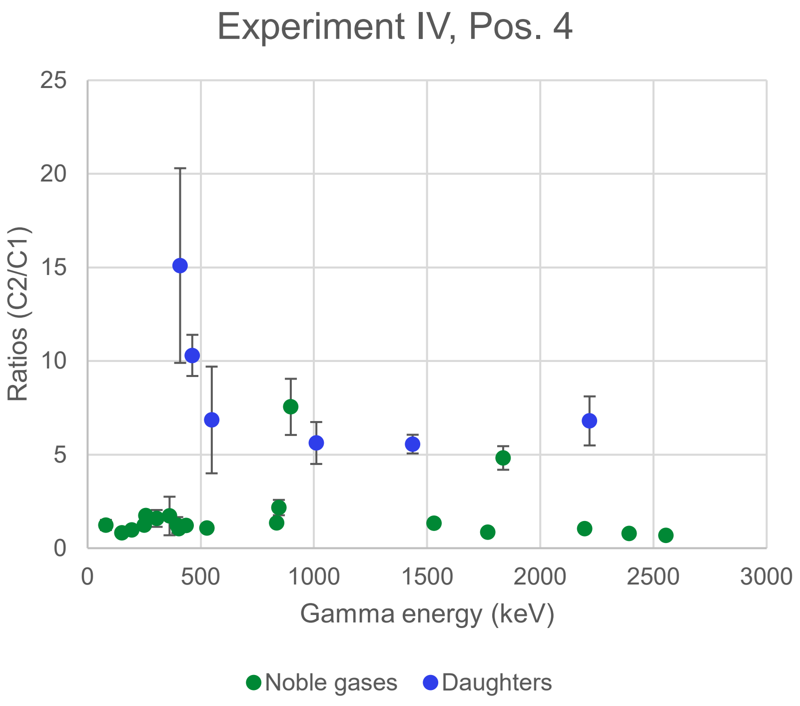
- The gamma-spectrometer results showed unexpectedly a consistent significant surplus of the radioactive decay products of the noble gases relative to the noble gases themselves. This was interpreted as dry deposition of the non-gaseous decay products on vegetation and on the ground.
- The deposition velocities estimated to account for the surplus of the noble gas decay products were relatively high (2-10 cm/s), but not unphysical considering the circumstances (surface roughness and wind speed).

Ratios of concentrations of radionuclides in the air C2/C1

The concentrations C1 are derived from SF_6-measurements and release rates of noble gases from the stack combined with decay and ingrowth of gases and daughters. The concentrations C2 are derived from the gamma-spectrometric measurements and a semi-infinite cloud model







Conclusions 1

- The experiments show advantages and shortcomings of the Gaussian plume model. Among the advantages is the ability to calculate concentrations and doses with a simple mathematical model, and among the shortcomings are the meteorological assumptions which often do not apply well to reality. Furthermore, the experiments illustrate that even when the horizontal plume dispersion is well approximated by a Gaussian distribution, this may not be the case for the vertical distribution.
- One fundamental difference between the measurements of concentrations and radiation is that the air samples are collected at individual locations whereas the radiation is detected from a huge volume of air (and ground) surrounding the detector.

Conclusions 2

- The measured concentrations in experiment I and IV are somewhat higher than the models can account for. This is believed to be due to non-Gaussian vertical distributions. The measured exposure rates compare better with the calculated values. The reason for this is that these calculations were made with the estimated deposition velocities, and the noble gas daughters deposited on the ground contribute up to 35% of the exposure rate from the plume.
- Calculations were made of concentrations and exposure rates with standard parameters and with parameters estimated from the SF_6-measurements for both models. These results illustrate that when detailed information on the dispersion parameters is available, the stationary Gaussian plume models can predict concentrations and doses quite well. In most cases, however, when it is necessary to use standard dispersion parameters, the model predictions are less accurate.

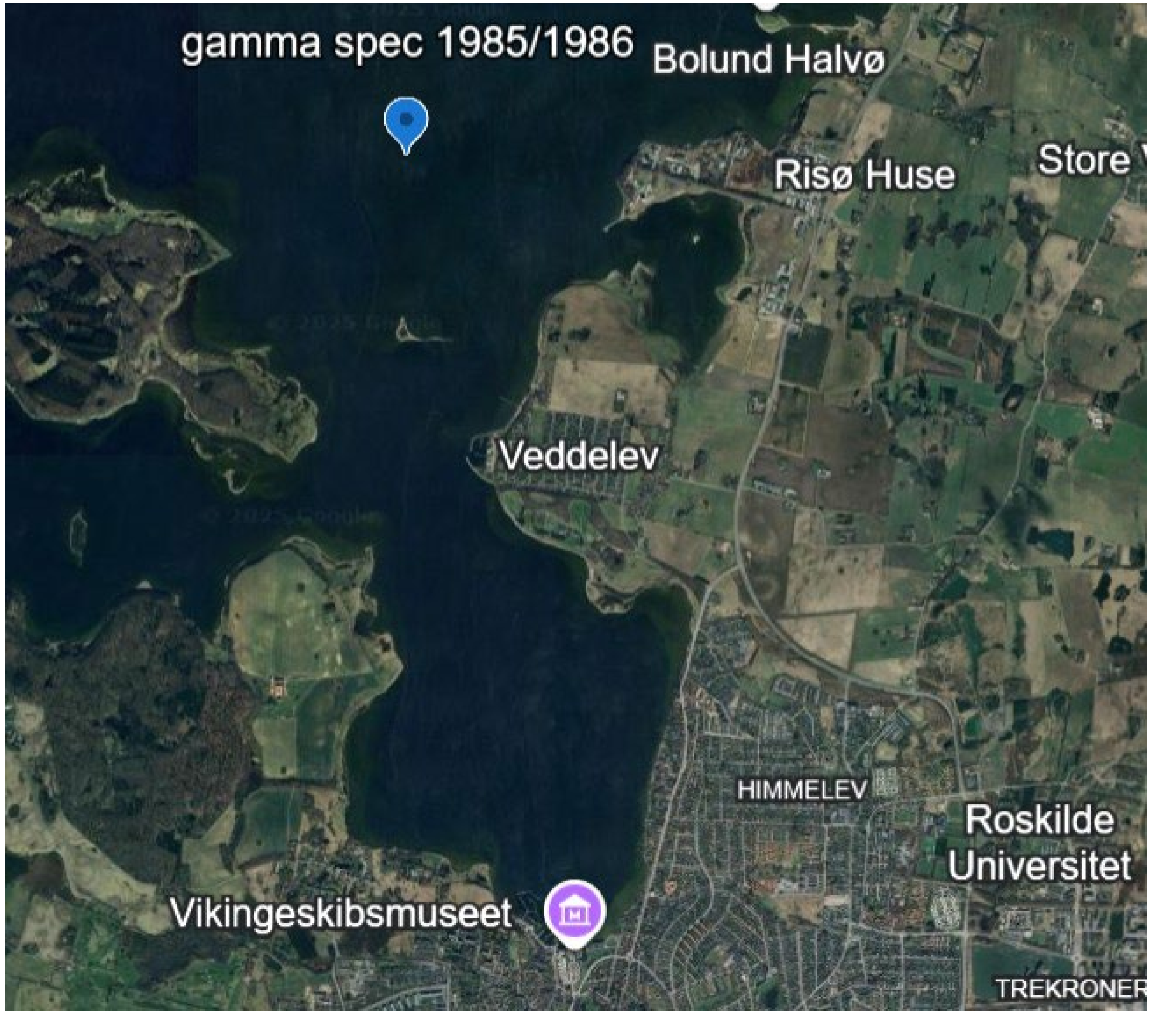
Ringhals team, May 1981

Field gamma-spectrometric measurements of airborne radionuclides over frozen water

- Short-lived radon daughters are always present in the near-ground atmosphere due to decay of the radon gas emanating from the soil surface.
- The airborne daughters are usually undetectable in connection with field gamma spectrometry, because radiation from the radon daughters in the soil dominates over the gamma radiation from the air.
- For the present measurements this terrestrial component was effectively eliminated due to the location far from land and the shielding of ice and water.

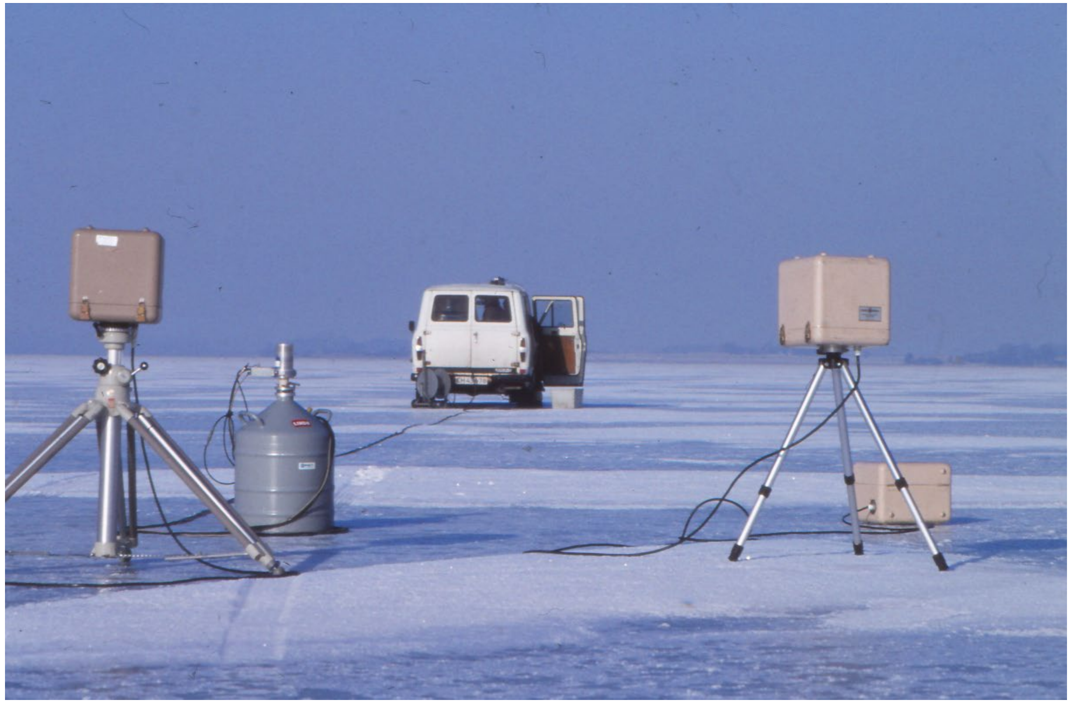
Experimental site

- On four occasions during the cold winters of 1985 and 1986, the opportunity was used to carry out measurements of the natural background radiation on the ice in the middle of Roskilde Fjord at Risø National Laboratory
- The measurements were made about 1.5 km from the shore at a location where the water depth is about 4.5 m
- During all measurements, the air-ice interface provided a nearly perfect smooth plane only partly covered with snow of up to a few centimetres thickness
- The thickness of the ice varied between 25 and 35 cm



Instrumentation 1

- The instruments were carried in a motor vehicle furnished for supplying electrical power for the equipment.
- The gamma spectrometric equipment comprised a Ge detector from Princeton Gamma Tech connected to a hard-wired Canberra Series 8100 multichannel analyzer.
- Air samples were collected on glass-fibre filters during the gamma-spectrometric measurements. The alpha activities on these filter papers were measured immediately after sampling to determine the airborne concentrations of Po-218, Pb-214 and Bi-214. Air was drawn through the filter using a small displacement pump. The gross-alpha activity was measured with a traditional alpha (ZnS) detector connected to a sequential counter controlling three preset counting intervals.



Instrumentation 2

- The Ge detector was calibrated with gamma rays in the energy range 0-3 MeV which entered the detector from all directions, thus, covering source distributions in the upper and lower hemisphere relative to the detector. This calibration was made in connection with similar measurements of radionuclides in the upper and lower half space and is described in detail elsewhere (Ringhals experiments, 1986).
- The equipment and procedure used for collecting radon daughters on filter paper was designed for measuring indoor levels and not optimized for the low outdoor levels. For the first radon daughter measurement, we used a sampling and counting strategy identical to that from our indoor measurements. But due to the large statistical uncertainties arising from the few counts observed, we increased the sampling time as well as the counting time for the subsequent measurements.

Results of gamma-spectrometric measurements showing counts per 1000 seconds from full-energy peaks

Gamma-ray Energy (keV)	Isotope	Date of measurement and counting time: 16Jan1985 3600 s	17Jan1985 7000 s	13Feb1985 5313 s	27Feb1986 3444 s
295	^{214}Pb	19±16%	29±12%	22±17%	4.6±50%
352	^{214}Pb	23±16%	36± 9%	35±10%	18±16%
511	annihil.	18±17%	20±11%	22±12%	19±15%
609	^{214}Bi	20±15%	38± 7%	28±10%	9.1±15%
1120	^{214}Bi	2.8±51%	6.6±21%	3.3±38%	nd
1461	^{40}K	3.6±32%	4.0±27%	2.8±35%	2.3±45%
1765	^{214}Bi	3.1±35%	7.8±15%	4.9±24%	2.9±34%

nd: not detected

Radon daughters in the air (Bq/m3)

Alpha counting of air samples

Isotope	Date, Collection time, Counting time		
	17 Jan 1985 5 min coll. 30 min count	13 Feb 1985 10 min coll. 55 min count	27 Feb 1986 30 min coll. 55 min count
^{218}Po	7.6±7.5	4.1±2.0	0.8±2.9
^{214}Pb	4.1±2.4	3.1±0.3	0.9±0.3
^{214}Bi	2.3±2.5	1.5±0.5	0.6±0.4

Gamma-spectrometric measurements and the semi-infinite cloud model

Isotope	Date of measurement			
	16 Jan 1985	17 Jan 1985	13 Feb 1985	27 Feb 1986
^{214}Pb	2.4±0.3	3.6±0.3	3.3±0.3	1.3±0.2
^{214}Bi	1.6±0.2	3.4±0.2	2.3±0.2	0.9±0.2

Deposition of radon daughters on the ice

- For the three days in which the observations of airborne radon daughters can be compared it is noted that the differences between the results from alpha and gamma measurements are not statistically significant.
- However, the results from the gamma-spectroscopic measurements tend to give small but consistently higher values than those from the alpha counting, which may be interpreted as due to radiation from radon daughters deposited on the ice. If the small surplus of gamma radiation rom the radon daughters is explained by deposition on the ice, the surface concentrations may be calculated, and furthermore deposition velocities may be estimated to account for these levels.
- The estimated deposition velocities (which are positive, but not significantly different from zero) range from 0.02 to 0.5 cm/s , which lie within the expected range.

Conclusions

- Field gamma-spectrometric measurements with a germanium detector on the frozen Roskilde Fjord have demonstrated the sensitivity of this technique for detecting low levels of radionuclides in the air.
- The measured concentrations of airborne radon daughters are in good agreement with results obtained from alpha counting of collected air samples.
- In addition, the results give information on dry deposition of radon daughters to the ice.