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# Urban Gamma Spectrometry: Report 1

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### Abstract

This report contains the present status and results for the NKS UGS-project per 1 June 2006 for NKS partners DTU, Denmark, and STUK, Finland.

The Danish and Finnish CGS systems are not of similar types. The Danish CGS system(s) only make use of one Nal(TI) detector whereas the Finnish CGS system consists of several detectors, Nal(TI) and HPGe both and as an additional feature the Finnish detectors have position dependent different fields of view. Furthermore, the Finnish system is equipped with an air sampling system. In terms of operation, the Danish detector is located r on the rooftop whereas the Finnish detectors are located inside the vehicle.

The Finnish and the Danish team use different methods for data processing. STUK uses a hypothesis test method to get robust real time alarms (within 10 seconds) when significant peaks from a previously defined set of nuclides are detected. An alarm for a significantly elevated total pulse rate is sent if none of the predefined nuclides is identified. All data are stored to the LINSSI database, which facilitates easy data retrieval for post processing.

DEMA/DTU bases their calculations on full spectrum fitting using NASVD and the Danish software NucSpec. Source signals are found from spectrum fitting residuals or from stripping of energy windows – either by the standard 4-windows method or by a measurement based method where stripping factors for any window of interest can be derived from the measurements themselves.

A thorough description of the two systems and data processing methods (including mathematics) are described in this report.

For the Danish methods of data processing some comparisons have been made, but no final conclusion has been reached yet. Raw urban data has been investigated along with urban data sets to which source signals have been added and searched for.

For the Finnish method calibration plots of the minimum detection limits for two different detector types have been made so far, and survey significance plots from drives around Helsinki during the Athletics World Championship in 2005 are presented.

### Key words

Urban Carborne Gamma Spectrometry, Spectrum Stripping, Peak hypothesis, LINSSI, FSC, ASSS, NASVD

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# **URBAN GAMMA SPECTROMETRY**

## NKS Nordic Nuclear Safety Research

## Report 1 from the AFT/B(06)3 project group 01 June 2006

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### 1 SUMMARY

This report contains the present status and results for the NKS UGS-project per 1 June 2006. A comparison of the data treatment methods – Finnish method on Danish data material and vice versa -will take place in the second part of the project, which will also include data from SSI custom control CGS systems.

The Danish and Finnish CGS systems are not of similar types. The Danish CGS system(s) only make use of one NaI(Tl) detector whereas the Finnish CGS system consists of several detectors, NaI(Tl) and HPGe both and as an additional feature the Finnish detectors have position dependent different fields of view. Furthermore, the Finnish system is equipped with an air sampling system.

In terms of personnel, The Danish preference has been to have 3 simple CGS systems, that can be operated (with some introduction) by unskilled persons if necessary whereas the Finnish system is operated by experts.

In terms of operation, the Danish detector is located outdoor on the rooftop whereas the Finnish detectors are located inside the vehicle.

As a consequence of the different types and positions of detectors, one can say for certain that if the two different systems surveyed the same route, the results in terms of measurements would be far from identical.

The Finnish and the Danish teams use different methods for data processing.

STUK uses a hypothesis test method to get robust real time alarms (within 10 seconds) when significant peaks from a previously defined set of nuclides are detected. An alarm for a significantly elevated total pulse rate is sent if none of the predefined nuclides is identified. All data are stored to the LINSSI database, which facilitates easy data retrieval for post processing.

DEMA/DTU bases their calculations on full spectrum fitting using NASVD and the Danish software NucSpec. Source signals are found from spectrum fitting residuals or from stripping of energy windows – either by the standard 4-windows method or by a measurement based method where stripping factors for any window of interest can be derived from the measurements themselves.

Measurements from two different systems are available to be processed with three different data processing tools. This gives the participants a great opportunity to test the limits of their data processing methods that has previously only been used on own data material, i.e. are the data processing methods to be recommended for other users?

A thorough description of the two systems and data processing methods (including mathematics) are described in this report.

For the Danish methods of data processing some comparisons have been made, but no final conclusion has been reached yet. Raw urban data has been investigated along with urban data sets to which source signals have been added and searched for.

For the Finnish method calibration plots of the minimum detection limits for two different detector types have been made so far, and survey significance plots from drives around Helsinki during the Athletics World Championship in 2005 are presented.

### CONTENTS

1	SUMMARY	1
2	INTRODUCTION	4
3	DANISH CGS MEASUREMENTS	5
	3.1 The Danish CGS Systems	5
	3.1.1 Standard Windows and Energy Calibration	6
	3.1.2 File Layout	7
	3.2 CGS Data Treatment Tools	8
	3.2.1 Standard Software	8
	3.2.2 Non-standard Tools: Fitting with Spectral Components, FSC	10
	3.3 Data Processing Methods	11
	3.3.1 NASVD Noise Adjusted Singular Value Decomposition	11
	3.3.2 ASSS Area Specific Spectrum Stripping 2.3.2 ESC Fitting with Spectral Components	11
	3.4 Danish Data Files and Quality	13
	3.4.1 A rea017 spc	17
	3.4.2 Area051.spc	19
	3.4.3 Area052.spc	21
	3.4.4 Dose Rate Maps for Copenhagen Surveys	24
	3.5 Fitting Components	26
	3.5.1 Area17cl.spc	26
	3.5.2 Area051cl.spc	26
	3.5.3 Area052.spc	27
	3.6 Spectra for Search for Lost Sources.	29
	3.7 Spectra with Added Source Signals	30
	3.7.1 Area052cl.spc: Original Measurements	30
	5.7.2 Area052cl.spc with Added Source Signals	51
4	DANISH DATA TREATMENT WITH FSC	32
	4.1 FSC Reproduction versus NASVD Reconstruction	32
	4.2 Iterations	34
	4.3 FSC for File Area052.spc	36
	4.3.1 Count Rates for File Area052.spc	36
	4.3.2 FSC using Fitting Constants from File Area052.spc	37
	4.3.3 FSC using Fitting Constants from File Area051cl.spc	38
	4.3.4 FSC using Fitting Constants from File Area017cl.spc	39
	4.5.5 FSC using Fitting Constants from File Area052 spc: New NASVD Limits	40 41
	4.5.0 Comparison of FSC Results for File Area052.spc	41
5	DANISH AREA SPECIFIC STRIPPING OF FILE AREA052.SPC	41
6	DANISH RESULTS FOR FILE AREA052.SPC WITH ADDED SOURCE SIG	NALS

7	FINNI	SH CGS MEASUREMENTS	51
	7.1	The Finnish CGS System	51

9	9 REFERENCES				
8 ACRONYMS					
	7.6	Finnish data processing	59		
	7.5	Finnish Data Sets	57		
	7.4.2	In-house data Processing Methods	55		
	7.4.1	Standard Software	55		
	7.4	CGS Analysis Tools	55		
	7.3.1	Message Format - Example	53		
	7.3	XML-Format for Radiological Messages in In-Situ Measurements with Sonni	53		
	7.2	The LINSSI Database	52		

### **2 INTRODUCTION**

Urban gamma spectrometry has been given only minor attention with the focus being on rural gamma spectrometry. However, in recent years the Nordic emergency management agencies have turned focus towards border controls and the topic of lost sources. Gamma spectra measured in urban areas are characterized by a wide variety of spectrum shapes and very fast changes in environmental background values.

In 2004 a Danish CGS survey in the capitol Copenhagen took place. It was found that gamma spectrometry in urban areas is far more complicated to interpret than had previously been thought. Known and available methods of data processing were not enough to interpret the results and a new method "Fitting with Spectral Components", FSC, based on NASVD, was tested with some success. Yet, the method still needs a lot of improvement.

In Finland a database "LINSSI" has been developed for spectrum data. In CGS search mode a "peak hypothesis test" is applied to the measured spectra. This system was tested during the Helsinki 2005 Athletics World Championship and it provides fast and accurate automated alarms for intermediate and high level signals, but optimisation of detecting small signals is needed.

In Sweden mobile detector systems are used for border controls and problems are encountered when making measurement in harbour, container areas.

The aim of this project is to improve the methods handling data and for interpretation of urban gamma spectrometry measurements. The Finnish and Danish methods will be compared and tested on the same data sets from Copenhagen and Helsinki and, if available, SSI customs measurements with a possible combination of the two methods in mind. Data sets with and without source signals will be examined, with special emphasis on difficult background signals.

## **3 DANISH CGS MEASUREMENTS**

### 3.1 The Danish CGS Systems

The Danish CGS system is equipped with a 4L NaI(Tl) of dimensions  $16"\times4"\times4"(40.64 \text{ cm}\times10.16 \text{ cm}\times10.16 \text{ cm})$  and a GR-320 spectrometer. The system runs with the software 660Rover. The hardware and the software both originate from SAIC (Exploranium).

The detector is positioned on the roof top of the car at a height of 2.2 m to the passenger's site, i.e. closest to the roadside (DK: right side of the road).

The detector encapsulation is stainless steel of thickness 0.25 mm. The detector box itself is made of aluminium with thickness approximately 1.5 mm. Inside the detector box is a layer of 2 cm polyurethane foam. In 2004 the detector box was given an additional cover in the form a "box for skiing equipment" to protect the system (smelting water in winter, slower temperature changes). Figure 3.1.1 shows the detector position relative to the car.



Figure 3.1.1. Danish CGS system. Top, side and back view. (Ref. 1)

The system is stabilised on a Th-calibration source for normal operation (2614 keV in channel 418), but the possibility of stabilising using a <sup>137</sup>Cs source exists for measurements in contaminated areas. All spectra are stored as binary data including GPS positions.

The standard spectrometer mode is the MCA mode with 512-channels spectra with a sampling frequency of approximately 2-s real time. The measurement time can be changed. CGS measurements from the early years, however, only include 1-s real time 256-channels spectra.

The software includes the features of on-line (slightly delayed) count rates, stripped count rates and dose rates. The XY track lines can also be verified during operation. The data are present on screen either as a moving vertical bar showing count rate fluctuations or as a rainbow plot with colour coded pixels representing either high or low count rates. Upon request, a single spectrum can be shown separately for a further evaluation and compared with another (chosen prior to the comparisons) spectrum.

The system alarm level can be chosen manually and changed during operation. If a window count rate or a total dose rate, for example, exceeds the level, the alarm will be displayed. One of the newer features is temperature logging at the detector crystal to check for non-temperature stabilisation that could possibly introduce spectrum drift in the measurements.

There are two functional Danish CGS systems, B11 and B12, and a replacement system. The data used in this report were made with system B12.

#### 3.1.1 Standard Windows and Energy Calibration

The 512-channels Danish CGS systems have approximately the same energy calibration based on the full energy peak from <sup>137</sup>Cs in channel 110 (662 keV) and the full energy peak from <sup>208</sup>Tl in channel 418 (2615 keV).

The average energy calibration for the systems is:

$$E\gamma = 0.00057 \cdot (chn)^2 + 6.05451 \cdot (chn) - 13.53113 \text{ keV}$$

All energies refer to the centre of a channel and first channel is channel 0.

Radionuclide	LL (chn)	LL(keV)	UL(chn)	UL(keV)			
Cs	100	598	120	721			
Κ	222	1359	253	1555			
U	267	1644	299	1848			
Th	386	2408	449	2820			

Table 3.1.1.1. Standard radionuclide window.

Table 3.1.1.2.	Background	count rates	and sensitiviti	es
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Radionuclide	Background (cps)	Sensitivity	Sensitivity unit
Cs	4.73	20.30	$kBq/m^2 (ESC)^*$
K	2.43	28.25	cps / %
U	1.32	3.804	cps / ppm eU
Th	0.89	1.771	cps / ppm eTh

\*Equivalent Surface Concentration.

Table 3.1.1.3. Standard windows stripping factors.

a	b	g	α	β	γ	δ	3	ζ
0.0537	0	0	0.336	0.442	0.833	2.072	2.776	0.341

The following windows are used with FSC calculations and ASSS calculations (Ref. 2).

No	LL (chn.)	UL (chn.)	LL (keV)	UL (keV)	
0	User's choice	User's choice	-	-	-
1	20	40	107	230	<sup>199</sup> Tcm
2	48	65	278	382	Scatter
3	50	70	291	413	Scatter
4	55	72	321	425	<sup>131</sup> I
5	100	120	598	721	<sup>137</sup> Cs
6	180	220	1095	1346	<sup>60</sup> Co
7	222	253	1359	1555	K
8	267	299	1644	1848	U
9	386	449	2408	2820	Th
10	20	240	107	1472	Total_1
11	20	435	107	2728	Total 2

*Table 3.1.1.4.*  $\Delta^2$ *-windows for the FSC and ASSS method.* 

Window 10 ends at the <sup>40</sup>K centroid and window 11 ends after the Th-peak.

#### 3.1.2 File Layout

The following Exploranium data layout (layout 3), ref. 17 June 2003 GR660 version 6.0, is valid for the Danish CGS files:

Header 547 bytes Struct 1152 bytes: unsigned long Record number; unsigned long Line number; double UTC time; double X; double Y; double Z; double Northing; double Easting; float PDOP; long DGPS; float ralt; float Live time; float roi[10]; short gain short peak int clock time char spare[8]; unsigned int SPC[512];

X, Y, Z are GPS ECEF-co-ordinates.

UTC time is seconds since 1. January 1970, PC time dependent.

### 3.2 CGS Data Treatment Tools

#### 3.2.1 Standard Software

The standard software tool for post-processing of Danish CGS data is the program NUCSpec developed in corporation between the Danish Emergency Management Agency and Prolog Development Centre (Copyright PDC).



Figure 3.2.1.1. NUCSpec screen dump.

The earliest version only allowed for AGS (Airborne Gamma Spectrometry) measurements but the newer versions are for AGS and CGS both. A few years ago the NASVD (Noise Adjusted Single Value Decomposition) method invented by Dr. Jens Hovgaard was supplied upon request as a special NUCSpec feature. The latest version of NUCSpec also includes the method of ASSS (Area Specific Spectrum Stripping). NASVD and ASSS are not necessary in order to run NUCSpec but are separate dll files. This report will include a short discussion of measurements investigated by the ASSS method.

File	Description
NUCSpec.exe	The main program – always needed
Nasvddlll.dll	A DLL for running the NASVD program
Mapdll.dll	A DLL for running the MAP program
Projections.def	A text file defining the projections available in NUCSpec
Positions.def	A tects file defining the geographical positions of the PMS stations
Default.xml	A default setup file
DefaultASS.xml	A default area specific stripping setup file

Table 3.2.1. The NUCSpec program structure.

The basic program facilities are the standard 4-windows-stripping method for Th, U, K and <sup>137</sup>Cs concentrations, calculation of air kerma rates based on SDI-values, plotting of track lines and creation of colour maps for direct export to MapInfo.

NucSpec	A 1		
E Color		1999-00 19 19 19	
<ul> <li>Windows</li> </ul>		Stripping: General:	
E Stripping		Alpha:	0.336
Alpha		Beta:	0.442
- Gamma	=	Gamma:	0.833
Delta Epsilon		Delta:	2.072
Zeta		Epsilon:	2.776
- a - b		Zeta:	0.341
g ⊕ HeightAttenuation	1	a:	0.0537
		b:	0
E SensitivityGround	•	g:	0

Figure 3.2.1.2. NUCSpec CGS stripping factors.

Destroyed spectra can be deleted from the data files and selections of data saved as new data files. It is also possible to extract single spectra in text file layout. NASVD treatment of data before the calculations take place will eliminate "noise" to a large extent: groups of spectra are divided into a number of spectral shapes and the shapes are then recombined according to the users' choice, e.g. the mean spectrum can be subtracted from all spectra. The relatively new ASSS feature (Ref. 3, 4) provides the possibility for extracting stripping factors for any radionuclide window directly from a set of measured data instead of using pre-calculated values.

C:\Miniprog\NUCspec\'	1 6ma	05\defaultASS.xml (Read-Only!)	×
<ul> <li>Information</li> <li>Windows</li> <li>Stripping</li> <li>General</li> <li>Alpha</li> <li>Beta</li> <li>Gamma</li> <li>a</li> <li>b</li> <li>g</li> <li>A litude</li> <li>AltitudeUnit</li> </ul>		Stripping:General:Alpha:0Beta:0Gamma:0a:0b:0g:0A:0B:0C:0	
Close Reload	Minipro	Save and Apply Apply Only Save As a)NUCspec\16mar05\defaultAS5.xml	

Figure 3.2.1.3. NUCSpec Area Specific Stripping.

#### 3.2.2 Non-standard Tools: Fitting with Spectral Components, FSC

This method is not a part of the standard processing tool pack NUCSpec, but may be included in the future. The Danish Permanent Monitoring Stations, PMS, are equipped with a slightly similar fitting procedure, but fitting with two or three components only. The FSC method has been tested with stationary measurements from the PMS station at DTU (research station only) with very good results (Ref. 5). Recently the method was tried on a very small selection of spectra measured in the central part of Copenhagen (Ref. 6). The results were promising, but more work needs to be done to perform an evaluation of the method in an environment where the spectrum shapes changes constantly.

The FSC method consists of a series of small programs written in Microsoft Visual Studio C<sup>++</sup> NET 2003 (Microsoft Development Environment Version 7.1.3088). Dr. Jens Hovgaard (Radiation Solutions Inc.) kindly supplied the matrix inversion procedure in the program FSC\_2006.

The programs are:

- CGSdif Creates a difference spectrum for two CGS measurements. The outputs are a binary file containing a 512-channels spectrum (1024 bytes, short integers) and txt file containing the two chosen spectra and their difference. The program is for 512-channels CGS data. Adds a binary 512-channels spectrum without header (1024 bytes, short SpecAdd integers) to a spectrum in a 512-channels CGS data file. The spectrum can be added several times to different spectrum numbers. A multiplication factor of 0 will result in no addition. Data are saved in CGS layout 3 (header 547 bytes and spectrum struct 1152 bytes). Txt2Bin Translates a 512-channels spectrum text file to a 512-channels binary spectrum file that can be used with SpecAdd. FSC 2006 Main fitting program In order to run the program the following files must be available: A file containing up to a maximum of 10 spectral components. The first column contains the mean spectrum,  $s_0$ . A file with the measured data. The data format should be Danish CGS layout. The outputs from the main fitting programs are:
- Fitting file Number of runs, lower channel for fitting, upper channel for fitting, fitting constants,  $\Delta^2$ -values, co-ordinates, UTC time and live time. The  $\Delta^2$ -windows are based on the windows used in the Barents Rescue Exercise, Boden, Sweden, 2001 and cannot be changed. One additional voluntary window is possible.
- Spectra file Spectrum number, the measured spectrum, the weight factor, the reproduced spectrum, the difference spectrum and the live time in seconds.

#### 3.3 Data Processing Methods

#### 3.3.1 NASVD Noise Adjusted Singular Value Decomposition

The method was introduced by J. Hovgaard in 1997 and information on the basic properties and the applications of the NASVD technique can be studied in Ref 7, 8 and 9.

The measured spectra are decomposed into a set of spectral components. The first spectral component  $s_0$  is the mean spectrum containing the background. For each measured spectrum is determined the amount – the amplitude  $b_{i,j}$  – of each spectral components  $s_i$  that should be included in a best fit of the measured spectrum.

For most natural data sets all spectra can be reconstructed by using only the mean spectrum  $s_0$  and five additional spectral components i.e. there is no important information in  $s_6$ ,  $s_7$  etc. The reconstructed spectrum number i -  $r_i$  – is therefore calculated as:

$$\mathbf{r}_{i} = \mathbf{s}_{0} + (\mathbf{b}_{i,1}\mathbf{s}_{1} + \mathbf{b}_{i,2}\mathbf{s}_{2} + \mathbf{b}_{i,3}\mathbf{s}_{3} + \mathbf{b}_{i,4}\mathbf{s}_{4} + \mathbf{b}_{i,5}\mathbf{s}_{5})/LT_{i}$$
(3.3.1.1)

 $b_{i,j}$  is the amplitude (amount) of spectral component No. j to be included in the reconstruction and  $LT_i$  is the live time for measurement No. i.

#### 3.3.2 ASSS Area Specific Spectrum Stripping

Consider a large number of CGS spectra that have been measured in an environment with varying concentrations of Th, U, and K. Significant measuring parameters as energy calibration is assumed constant during the measurements. Furthermore it is assumed that variations in air radon concentrations are few. Then by having three primary parameters - i.e. the concentrations of Th, U, and K - the count rate of any energy window of a spectrum can be described as a linear combination of the concentrations of Th, U, and K, i.e.:

$$\mathbf{r}_{l,i} = \alpha \mathbf{c}_{Th,i} + \beta \mathbf{c}_{U,i} + \gamma \mathbf{c}_{K,i} + \delta_i \tag{3.3.2.1}$$

Where  $r_{l,i}$  is the count rate of a low energy window for spectrum number i after subtraction of the background count rate.  $c_{Th,i}$  is the concentration of thorium in the surroundings corresponding to spectrum number i.  $c_{U,i}$  and  $c_{K,i}$  have similar meanings.  $\delta_i$  is the statistical error for Equation (3.3.2.1) caused by the Poisson statistics of the window counts.

The concentrations of Th, U, and K corresponding to spectrum number i can be determined from window count rates for the full energy peaks of Th (2615 keV), U (1764 keV) and K (1461 keV) and there are linear relations between those count rates and the concentrations (as used for the normal three-window method). Therefore the count rate of the low energy window also can be described as:

$$\mathbf{r}_{l,i} = \mathbf{a} \cdot \mathbf{r}_{Th,i} + \mathbf{b} \cdot \mathbf{r}_{U,i} + \mathbf{c} \cdot \mathbf{r}_{K,i} + \Delta_i$$
(3.3.2.2)

where  $r_{Th,i}$ ,  $r_{U,i}$  and  $r_{K,i}$  are the count rates of the "standard" windows for Th, U, and K respectively.  $\Delta_i$  is the statistical error for the equation caused by having statistical fluctuations for all four window count rates of Equation (3.3.2.2). The parameters a, b, and c are constants for a specific set of windows and, therefore, Equation (3.3.2.2) tells that the count rate of a low energy window can be described as a linear combination of the count rates of the other windows. The parameters a, b and c depend on the detector and its position in/on a car, on the energy calibration and on the channel numbers included in each window.

For a specific detector mounted in a specific way on/in a specific car etc. one will be able to extract the best parameters a, b and c from a large set of data by investigating the "error" F defined by:

$$F = \Sigma \Delta_{i}^{2} = \Sigma (r_{l,i} - a \cdot r_{Th,i} - b \cdot r_{U,i} - c \cdot r_{K,i})^{2}$$
(3.3.2.3)

The task now is to find the a, b, and c values that gives the smallest value of F. One may include a weight factor -  $w_i$  - as for example:

$$\mathbf{F} = \Sigma \Delta_i^2 \cdot \mathbf{w}_i = \Sigma \mathbf{w}_i \cdot (\mathbf{r}_{1,i} - \mathbf{a} \cdot \mathbf{r}_{Th,i} - \mathbf{b} \cdot \mathbf{r}_{U,i} - \mathbf{c} \cdot \mathbf{r}_{K,i})^2$$
(3.3.2.3a)

Here  $w_i$  is a weight factor that takes into account that  $\Delta_i^2$  varies from measurement to measurement (from spectrum to spectrum). Usually one uses a weight factor  $w_i$  that is inversely proportional to the variance of measurement No. i, i.e. one will have:

$$\mathbf{F} = \Sigma \Delta_i^2 / \operatorname{var}_i = \Sigma (\mathbf{r}_{l,i} - \mathbf{a} \cdot \mathbf{r}_{Th,i} - \mathbf{b} \cdot \mathbf{r}_{U,i} - \mathbf{c} \cdot \mathbf{r}_{K,i})^2 / \operatorname{var}_i$$
(3.3.2.3b)

A weight factor  $w_i$  is not included in the calculations described below. The reason is that for measurements in a normal environment the count rates will not vary much more that a factor 2. However, an inclusion of a weight factor is a simple matter. One at first finds some preliminary values of a, b, and c without using a weight factor. Then by using the preliminary values one calculates the variance for  $(r_{l,i} - a \cdot r_{Th,i} - b \cdot r_{U,i} - c \cdot r_{K,i})$  and includes it into Equation (3.3.3.2b) and then calculates new values for a, b, and c.

[By not including a weight factor in the calculations the spectra with high count rates will get a somewhat too large influence on the results. If the measuring geometry is the same for all spectra - and only the concentrations vary - this is without influence. However, if varying concentrations are correlated to varying measuring geometry a minor error may come up. But practical experiences with strongly varying geometry and concentrations indicate that the error is in the order of 1%.]

Now by using the Equation (3.3.2.3) for minimising F by varying the values of a, b, and c one gets:

$dF/da = 2 \cdot \Sigma(-r_{Th,i}) \cdot (r_{I,i} - a \cdot r_{Th,i} - b \cdot r_{U,i} - c \cdot r_{K,i}) = 0$	(3.3.2.4)	1)
$dF/db = 2 \cdot \Sigma(-r_{U,i}) \cdot (r_{I,i} - a \cdot r_{Th,i} - b \cdot r_{U,i} - c \cdot r_{K,i}) = 0$	(3.3.2.4)	3)

 $dF/dc = 2 \cdot \Sigma(-\mathbf{r}_{K,i}) \cdot (\mathbf{r}_{Li} - \mathbf{a} \cdot \mathbf{r}_{Th,i} - \mathbf{b} \cdot \mathbf{r}_{U,i} - \mathbf{c} \cdot \mathbf{r}_{K,i}) = 0$ (3.3.2.4c)

The equations can now be rewritten to:

$$\mathbf{a} \cdot \Sigma \mathbf{r}_{\mathrm{Th},i}^{2} + \mathbf{b} \cdot \Sigma \mathbf{r}_{\mathrm{Th},i} \cdot \mathbf{r}_{\mathrm{U},i} + \mathbf{c} \cdot \Sigma \mathbf{r}_{\mathrm{Th},i} \cdot \mathbf{r}_{\mathrm{K},i} = \Sigma \mathbf{r}_{\mathrm{I},i} \cdot \mathbf{r}_{\mathrm{Th},i}$$
(3.3.2.5a)

 $\mathbf{a} \cdot \Sigma \mathbf{r}_{\mathrm{Th},i} \cdot \mathbf{r}_{\mathrm{U},i} + \mathbf{b} \cdot \Sigma \mathbf{r}_{\mathrm{U},i}^{2} + \mathbf{c} \cdot \Sigma \mathbf{r}_{\mathrm{U},i} \cdot \mathbf{r}_{\mathrm{K},i} = \Sigma \mathbf{r}_{\mathrm{I},i} \cdot \mathbf{r}_{\mathrm{U},i}$ (3.3.2.5b)

 $a \cdot \Sigma r_{\text{Th},i} \cdot r_{\text{K},i} + b \cdot \Sigma r_{\text{U},i} \cdot r_{\text{K},i} + c \cdot \Sigma r_{\text{K},i}^{2} = \Sigma r_{\text{I},i} \cdot r_{\text{K},i}$ (3.3.2.5c)

The practical way of solving the equations by a computer program is to calculate a set of new parameters, namely:

$$TT = \Sigma r_{Th,i}^{2} UU = \Sigma r_{U,i}^{2} KK = \Sigma r_{K,i}^{2}$$

$$TU = \Sigma r_{Th,i} \cdot r_{U,i} TK = \Sigma r_{Th,i} \cdot r_{K,i} UK = \Sigma r_{U,i} \cdot r_{K,i}$$

$$LT = \Sigma r_{I,i} \cdot r_{Th,i} LU = \Sigma r_{I,i} \cdot r_{U,i} LK = \Sigma r_{I,i} \cdot r_{K,i}$$
(3.3.2.6)

Finally one may define a matrix **H** and the column vectors **v** and **w** by:

$$\begin{array}{cccccccc} TT & TU & TK & a & LT \\ \mathbf{H} = TU & UU & UK & \mathbf{v} = b & \mathbf{w} = LU \\ TK & UK & KK & c & LK \end{array}$$
(3.3.2.7)

Now (3.3.2.5) can be written as:

 $\mathbf{H}\mathbf{v} = \mathbf{w}$  or  $\mathbf{v} = \mathbf{H}^{-1}\mathbf{w}$ , from where a, b, and c can be determined.

Next assume that a, b, and c has been determined for a large set of spectra. One now investigates the original formula:

$$\mathbf{r}_{l,i} = \mathbf{a} \cdot \mathbf{r}_{Th,i} + \mathbf{b} \cdot \mathbf{r}_{U,i} + \mathbf{c} \cdot \mathbf{r}_{K,i} + \Delta_i \tag{3.3.2.1}$$

rewritten to:

$$\Delta_{i} = \mathbf{r}_{1,i} - \mathbf{a} \cdot \mathbf{r}_{Th,i} - \mathbf{b} \cdot \mathbf{r}_{U,i} - \mathbf{c} \cdot \mathbf{r}_{K,i}$$
(3.3.2.8)

For a normal environment - and perfect equipment - the  $\Delta_i$  values will scatter around zero when going from one spectrum to the next. For a real world situation one may have spectrum drift causing  $\Delta_i$  having somewhere mostly positive values and somewhere mostly negative values. Changes in measuring geometry also influence the result (slightly). If, however, a low energy emitter has added a signal to a sequence of spectra - for example when bypassing a point source with a low energy gamma emitter - then the  $\Delta_i$  values will - when plotted spectrum by spectrum exhibit a short peak above the general level.

One may include all spectra in the calculations - also spectra that are "suspected for carrying a signal from a low energy emitter. One then obtains "erroneous" a, b, and c values and a plot of  $\Delta_i$  from Equation (3.3.3.8) will have a shift in level. However, the low energy emitter will yet show up with a peak.

In a search for unusual gamma radiation one may calculate sets of a, b, and c values for a number of low energy windows and investigate the corresponding  $\Delta_i$  values.

#### 3.3.3 FSC Fitting with Spectral Components

Least squares fitting of (city) CGS spectra with NASVD spectral components.

It is assumed that a set of CGS spectra has been decomposed into a number of spectral components by the NASVD technique.

For city CGS spectra the components will have to adjust for the intensity of radiation from Th + U and from K independently, and some spectrum drift usually also influences the spectrum shape. Therefore at least three spectral components are needed for reconstructions. In addition the "concentration" of Th and U may vary relative to each other whereby an additional spectral component is needed for the reconstructions. Finally the "geometry effect" in a city area will influence the spectrum shape - mostly at the lower energies. Therefore, in all at least five spectral components (+  $s_0$ ) will normally be needed for reconstruction of city CGS spectra.

It is now assumed that a new set of CGS spectra has been recorded in the same or a similar area with the same equipment. The new set of spectra therefore has to include the same spectrum shapes as the "old" set of spectra. Therefore each of the new spectra also can be fitted from suitable combinations of spectral components from the old set of spectra i.e. it is assumed that one may write:

$$\mathbf{n}_{i} = \mathbf{s}_{0} \cdot \mathbf{L} \mathbf{T}_{i} + \mathbf{c}_{i,1} \cdot \mathbf{s}_{1} + \mathbf{c}_{i,2} \cdot \mathbf{s}_{2} + \mathbf{c}_{i,3} \cdot \mathbf{s}_{3} + \mathbf{c}_{i,4} \cdot \mathbf{s}_{4} + \mathbf{c}_{i,5} \cdot \mathbf{s}_{5} + \mathbf{\delta}_{i}$$
(3.3.3.1)

 $\mathbf{n}_i$  is the measured "count spectrum" ( $\mathbf{n}_i = \mathbf{r}_i \cdot \mathbf{LT}_i$ ).  $\delta_i$  is the "errors" caused by statistical fluctuations. For convenience the term  $\mathbf{s}_0 \cdot \mathbf{LT}_i$  will be substituted by  $\mathbf{n}_0$  in the following text. For the Danish CGS systems the count period is 2 s including a "dead time" of approximately 0.07 s. Therefore, Eq. 3.3.3.1 refers to the counts for one standard Live Time period of approximately 1.9 s. The product  $\mathbf{s}_0 \cdot \mathbf{LT}_i$  should include the actual live time whereas the live time is without influence on the remaining part of the equation. The indices "i" tells that each new spectrum should have its own set of parameters  $c_1$ ,  $c_2$ ,  $c_3$ ,  $c_4$ , and  $c_5$  those parameters automatically take the live time into account.

One may also write that:

$$\delta_{i} = \mathbf{n}_{i} - \mathbf{n}_{0} - c_{i,1} \cdot \mathbf{s}_{1} - c_{i,2} \cdot \mathbf{s}_{2} - c_{i,3} \cdot \mathbf{s}_{3} - c_{i,4} \cdot \mathbf{s}_{4} - c_{i,5} \cdot \mathbf{s}_{5}$$
(3.3.2)

As with the ASSS method a weight factor, w<sub>i</sub>, can be applied.

The task now is to find the combination of  $c_1$ -,  $c_2$ -,  $c_3$ -,  $c_4$ - and  $c_5$ -values that produces the best fit. The "best" fit is determined by the standard least squares fit i.e. by demanding that  $\Delta^2 - \Delta^2$  is defined as  $\Sigma \delta_i^2 \cdot w_i$  has its minimum value:

$$\Delta^{2}_{i} = \Sigma \left( n_{i,j} - n_{0,j} - c_{1} \cdot s_{1,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3,j} - c_{4} \cdot s_{4,j} - c_{5} \cdot s_{5,j} \right)^{2} \cdot w_{i,j}$$
(3.3.3)

The summation (over j) covers all channels of interest. (For a 511 channels spectrum the summation may go from j = 20 to j = 480.)

 $w_{i,j}$  is a weight factor that should be assigned to element number j in the summation i.e. each channel counts. According to standard theory the weight factor should be inverse proportional to the variance -  $Var(n_{i,j})$  - of the element  $n_{i,j}$  (Ref. 10).  $s_0$ ,  $s_1$ ,  $s_2$ ,  $s_3$ ,  $s_4$  and  $s_5$  are assumed to be without uncertainty.

For a Poisson distribution the Var( $n_{i,j}$ ) is equal to the "expected" value of  $n_{i,j}$ . However, for simplicity the mean value for the set of "base" spectra -  $s_0$ · LT<sub>i</sub> - is used instead. This introduces an error that is neglected here. (A reason for not using the measured spectrum for the weight, i.e.  $w_{i,j} = 1/n_{i,j}$  is that the number of measured counts -  $n_{i,j}$  - may be zero.)

Eq. 3.3.3.3 is therefore replaced by:

$$\Delta^{2}_{i} = \Sigma \left( n_{i,j} - n_{0,j} - c_{1} \cdot s_{1,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3j} - c_{4} \cdot s_{4j} - c_{5} \cdot s_{5j} \right)^{2} / n_{0,j}$$
(3.3.3.4)

The task therefore is to minimise  $\Delta^2_i$  by varying  $c_1$ ,  $c_2$ ,  $c_3$ ,  $c_4$ , and  $c_5$  i.e. one has to demand that:

$$d(\Delta^2)/dc_1 = 0; \ d(\Delta^2)/dc_2 = 0; \ d(\Delta^2)/dc_3 = 0; \ d(\Delta^2)/dc_4 = 0 \text{ and } d(\Delta^2)/dc_5 = 0$$
 (3.3.3.5)

(The summation covers all channel numbers "j" of interest)

$$d (\Delta^{2})/dc_{1} = d \{ \Sigma (n_{i,j} - n_{0,j} - c_{1} \cdot s_{1,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3,j} - c_{4} \cdot s_{4,j} - c_{5} \cdot s_{5,j})^{2}/n_{0,j} \}/dc_{1}$$
(3.3.3.6)  
$$= d \{ \Sigma [(n_{i,j} - n_{0,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3,j} - c_{4} \cdot s_{4,j} - c_{5} \cdot s_{5,j})^{2} - 2c_{1} \cdot s_{1,j} \cdot (n_{i,j} - n_{0,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3,j} - c_{4} \cdot s_{4,j} - c_{5} \cdot s_{5,j}) + c_{1}^{2} \cdot s_{1,j}^{2}]/n_{0,j} \}/dc_{1}$$
$$= \Sigma [0^{2} - 2 \cdot s_{1,j} \cdot (n_{i,j} - n_{0,j} - c_{2} \cdot s_{2,j} - c_{3} \cdot s_{3,j} - c_{4} \cdot s_{4,j} - c_{5} \cdot s_{5,j}) + 2c_{1} \cdot s_{1,j}^{2}]/n_{0,j}$$
Therefore:

$$d (\Delta^{2})/dc_{1} = \begin{bmatrix} -\Sigma 2 \cdot s_{1,j} \cdot (n_{i,j} - n_{0,j}) + 2c_{2} \cdot \Sigma s_{1,j} \cdot s_{2,j} + 2c_{3} \cdot \Sigma s_{1,j} \cdot s_{3,j} + 2c_{4} \cdot \Sigma s_{1,j} \cdot s_{4,j} \\ + 2c_{5} \cdot \Sigma s_{1,j} \cdot s_{5,j} + 2c_{1} \cdot \Sigma s_{1,j}^{2} \end{bmatrix} / n_{0,j} = 0$$
  
$$= -\Sigma 2 \cdot s_{1,j} \cdot (n_{i,j} - n_{0,j}) / n_{0,j} + 2c_{2} \cdot \Sigma s_{1,j} \cdot s_{2,j} / n_{0,j} + 2c_{3} \cdot \Sigma s_{1,j} \cdot s_{3,j} / n_{0,j} \\ + 2c_{4} \cdot \Sigma s_{1,j} \cdot s_{4,j} / n_{0,j} + 2c_{5} \cdot \Sigma s_{1,j} \cdot s_{5,j} / n_{0,j} + 2c_{1} \cdot \Sigma s_{1,j}^{2} / n_{0,j} = 0$$

or

$$c_{2} \cdot \Sigma s_{1,j} \cdot s_{2,j}/n_{0,j} + c_{3} \cdot \Sigma s_{1,j} \cdot s_{3,j}/n_{0,j} + c_{4} \cdot \Sigma s_{1,j} \cdot s_{4,j}/n_{0,j} + c_{5} \cdot \Sigma s_{1,j} \cdot s_{5,j}/n_{0,j} + c_{1} \cdot \Sigma s_{1,j}^{2}/n_{0,j} = \Sigma s_{1,j} \cdot (n_{i,j} - n_{0,j})/n_{0,j}$$
(3.3.3.7)

$$d (\Delta^{2})/dc_{2} \Rightarrow a \cdot \Sigma s_{2,j} \cdot s_{1,j}/n_{0,j} + c_{3} \cdot \Sigma s_{2,j} \cdot s_{3,j}/n_{0,j} + c_{4} \cdot \Sigma s_{2,j} \cdot s_{4j}/n_{0j} + c_{5} \cdot \Sigma s_{2,j} \cdot s_{5,j}/n_{0,j} + c_{2} \cdot \Sigma s_{2,j}^{2}/n_{0,j} = \Sigma s_{2,j} \cdot (n_{i,j} - sn_{0,j})/n_{0,j}$$
(3.3.3.8)

$$d (\Delta^{2})/dc_{3} \Rightarrow c_{2} \cdot \Sigma s_{3,j} \cdot s_{2,j}/n_{0,j} + c_{1} \cdot \Sigma s_{3,j} \cdot s_{1,j}/n_{0,j} + c_{4} \cdot \Sigma s_{3,j} \cdot s_{4,j}/n_{0,j} + c_{5} \cdot \Sigma s_{3,j} \cdot s_{5,j}/n_{0,j} + c_{3} \cdot \Sigma s_{3,j}^{2}/n_{0,j}$$
  
=  $\Sigma s_{3,j} \cdot (n_{i,j} - n_{0,j})/n_{0,j}$  (3.3.3.9)

 $d (\Delta^2)/dc_4 \Rightarrow$ 

 $d (\Delta^2)/dc_5 \Rightarrow$ 

$$c_{2} \cdot \Sigma s_{4,j} \cdot s_{2,j}/n_{0,j} + c_{3} \cdot \Sigma s_{4,j} \cdot s_{3,j}/n_{0,j} + c_{1} \cdot \Sigma s_{4,j} \cdot s_{1j}/n_{0,j} + c_{5} \cdot \Sigma s_{4,j} \cdot s_{5,j} / n_{0,j} + c_{4} \cdot \Sigma s_{4,j}^{2} / n_{0,j}$$

$$= \Sigma s_{4,j} \cdot (n_{i,j} - n_{0,j}) / n_{0,j}$$
(3.3.3.10)

$$c_{2} \cdot \Sigma s_{5,j} \cdot s_{2,j}/n_{0,j} + c_{3} \cdot \Sigma s_{5,j} \cdot s_{3,j}/n_{0,j} + c_{1} \cdot \Sigma s_{5,j} \cdot s_{1,j}/n_{0,j} + c_{4} \cdot \Sigma s_{4,j} \cdot s_{5,j}/n_{0,j} + c_{5} \cdot \Sigma s_{5,j}^{2}/n_{0,j}$$

$$= \Sigma s_{5,j} \cdot (n_{i,j} - n_{0,j})/n_{0,j}$$
(3.3.3.11)

From the equations (3.3.3.7) to (3.3.3.11) one then gets the best fit for the new measured spectrum number "i" by using the calculated  $c_1$ ,  $c_2$ ,  $c_3$ ,  $c_4$ , and  $c_5$  values.

$$\mathbf{n}_{i} = \mathbf{n}_{0} + \mathbf{c}_{i,1} \cdot \mathbf{s}_{1} + \mathbf{c}_{i,2} \cdot \mathbf{s}_{2} + \mathbf{c}_{i,3} \cdot \mathbf{s}_{3} + \mathbf{c}_{i,4} \cdot \mathbf{s}_{4} + \mathbf{c}_{i,5} \cdot \mathbf{s}_{5} + \mathbf{\delta}_{i}$$
(3.3.3.1 repeated)

The equations (3.3.3.7) to (3.3.3.11) can be written as:

$AA_{i,1} \cdot c_{i,1} + BB_{i,1} \cdot c_{i,2} + CC_{i,1} \cdot c_{i,3} + GG_{i,1} \cdot c_{i,4} + HH_{i,1} \cdot c_{i,5} = EE_{i,1}$	(3.3.3.12a)
$AA_{i,2} \cdot c_{i,1} + BB_{i,2} \cdot c_{i,2} + CC_{i,2} \cdot c_{i,3} + GG_{i,2} \cdot c_{i,4} + HH_{i,2} \cdot c_{i,5} = EE_{i,2}$	(3.3.3.12b)
$AA_{i,3} \cdot c_{i,1} + BB_{i,3} \cdot c_{i,2} + CC_{i,3} \cdot c_{i,3} + GG_{i,3} \cdot c_{i,4} + HH_{i,3} \cdot c_{i,5} = EE_{i,3}$	(3.3.3.12c)
$AA_{i,4} \cdot c_{i,1} + BB_{i,4} \cdot c_{i,2} + CC_{i,4} \cdot c_{i,3} + GG_{i,4} \cdot c_{i,4} + HH_{i,4} \cdot c_{i,5} = EE_{i,4}$	(3.3.3.12d)
$AA_{i,5} \cdot c_{i,1} + BB_{i,5} \cdot c_{i,2} + CC_{i,5} \cdot 7c_{i,3} + GG_{i,5} \cdot c_{i,4} + HH_{i,5} \cdot c_{i,5} = EE_{i,5}$	(3.3.3.12e)

The indices "i" refer to the fact that each new spectrum should have its own calculations. The constants  $AA_{x,y}$  to  $HH_{x,y}$  are the same for all calculations; only the  $EE_{x,y}$  vary from spectrum to spectrum.

Then after having the values  $c_{i,1}$  to  $c_{i,5}$  for all spectra each spectrum could be reproduced according to Formula 3.3.3.1 i.e.:

$$\mathbf{n}_{i} = \mathbf{n}_{0} + \mathbf{c}_{i,1} \cdot \mathbf{s}_{1} + \mathbf{c}_{i,2} \cdot \mathbf{s}_{2} + \mathbf{c}_{i,3} \cdot \mathbf{s}_{3} + \mathbf{c}_{i,4} \cdot \mathbf{s}_{4} + \mathbf{c}_{i,5} \cdot \mathbf{s}_{5} + \mathbf{\delta}_{i}$$
(3.3.3.1 repeated)

In order to test the quality of the fit  $\delta_i$  should be evaluated.

$$\delta_{i} = \mathbf{n}_{i} - \mathbf{n}_{0} - c_{i,1} \cdot \mathbf{s}_{1} - c_{i,2} \cdot \mathbf{s}_{2} - c_{i,3} \cdot \mathbf{s}_{3} - c_{i,4} \cdot \mathbf{s}_{4} - c_{i,5} \cdot \mathbf{s}_{5}$$
(3.3.2 repeated)

The  $\delta_i$  values could be shown as an error spectrum and possibly one may discover if anomalous radiation is present. In order to get just one number expressing the quality of the fit one should calculate the sum of squared errors:

$$\Delta^{2} = \Sigma \, \delta_{i,j}^{2} \cdot w_{i,j} = \Sigma \, (n_{i} - n_{0} - c_{i,1} \cdot s_{1} - c_{i,2} \cdot s_{2} - c_{i,3} \cdot s_{3} - c_{i,4} \cdot s_{4} - c_{i,5} \cdot s_{5})^{2} \cdot w_{i,j}$$
(3.3.3.19)

If  $\Delta^2$  exceeds a certain value - found from experiences - the fit is of insufficient quality and the new measured spectrum contains unusual information.

The weight factor  $w_{i,j}$  should represent the uncertainty of each element of the summation. Therefore,  $w_{i,j}$  is selected as  $1/var(n_{i,j}) = 1/(n_{0,j} + a_i \cdot s_{1,j} + b_i \cdot s_{2,j} + c_i \cdot s_{3,j} + g_i \cdot s_{4,j} + h_i \cdot s_{5,j})$  The distribution of the results - the  $\Delta^2$  values - could be compared to a  $\chi^2$  distribution. If 461 channels are included in the fitting the degrees of freedom is 457 as five degrees have "been lost" by calculation of  $c_1$ ,  $c_2$ ,  $c_3$ ,  $c_4$ , and  $c_5$ .

#### 3.4 Danish Data Files and Quality

The following files contain 512-channels measurements from the Copenhagen area (UTM Zone 32, WGS84) and suburbs:

Area017.spc JanuarySystem B12Area17cl.spc (=Area017.spc excl. the first 200 spc.)Area051.spcArea052.spcSystem B12

Spectrum drift (temperature problems) Might include <sup>81</sup>Kr and <sup>41</sup>Ar signals. Good data quality. Good data quality.

#### 3.4.1 Area017.spc

The measurements were begun during heavy snowfall with the additional consequence of slow-moving traffic (including minor traffic jams) and ended in bright weather. The survey includes a drive around a hospital.

0-172	parked, back door of building 327 (Ørsted-DTU)	1001	Sct. Jacobs church to the right
172-196	driving to front end of build, 327	1020	behind parked car
215	department Elektrofysik 322 to the right	1039	stop for red at Trianglen
236-265	driving along Akademivei	1058	Øster Alle to the right
265	right turn to Toftegårdsvei	1070	Red Cross building
290	Statoil gasoline station to the right	1088	Rigshospitalet to the right
299	road crossing at Klampenborgyei	1099	turn toward Rigshospitalet Tagensvei
307	onto motorway	1120	main entrance to Rigshospitalet
353	road crossing at motorway/Jægersborgvei	1148	left turn towards cyclotron
360	left turn	1155	above cyclotron western direction
383	ston for red at Lægersborg Alle	1183	turning around
399	Smakkegårdsvei	1199	turned around
433	crossing Ermelundsvei	1203	exit from Finsen Institute to the right
4521	Smakkedal	1203	turning
466	Gentoftegade to the right	1250	exit from Rigshospitalet
400	sideroad to the left	1270	right turn to Blegdamsvei ston for red
510	crossing Adolphsvei. Tranegårdsvei	1270	Iuliane Mariesvei to the right
530	road crossing at Bernstorffsvei	1283-1319	ston for red road crossing Fredensgade/Tagensvei
553	Bernstorffsvei station to the right	1322-1334	Panum-instituttet to the right
561	Ingeborgvei to the left	1340	Skt Johannes Church to the right
570	Charlettenhundvoi to the left	1348 1365	Stop for red at Sankt Hanstory
576	Taffelbays Alle to the right	1370	Sankt Hans tory
584	stop for red at Gersonsvei	1300 1/10	stop for red at Emileduei/Narrebrogade
616	Ørshai	1390-1410	loft turn to Narrohrogado
627	Øregårdsparken to the left	1424	stop for red right before Dr. Louises bro (bridge)
620 648	of egal usparken to the feft	1424	on Dr. Louises hro (bridge)
649 995	Strondwaion, alongsido Ørogårdsnarkon	1458-1405	stop for rod at Satorvat
640-005	Uallarup Dark Hatal to the right	1407-1507	sight turn to Name Sacada
699	Dupterfoldts Alle to the right	1507 1568	along lakes (right side)
721	Managerathawai ta tha right	1507-1508	Traffic iom
721	Iomehoravoi to the left	1323-1329	SPECTDUM DISDI ACEMENT
740	Johnsborgvej to the right	1575 1632	Guldenlausgede, sten for red at Sanavillenen
740	Sentst Dadaravai to the right	1672-1662	Traffic iom
757	Callian server to the night	1625-1002	Traffic iom weite in line et Culdenslegwegede
/04	Callisensvej to the light	1000-	Vastar Farimagagada to the right
770	gasonne station to the left	1842-18/9	Vester Fanmagsgade to the light
//9	Stop for red at 1 uborgvej	1040	
800	I uborg mask building to the left	1949	on bridge above railway
014	Strenders to the left	1965-2004	ieit tuili
850	Strandøre to the felt	2013	right turn to vester volagade
851 850 804	Usteried to the right	2030	Crossing Studiestræde?
839-894	stop for red at road crossing, Jagivejen	2041	Politiken (newspaper domicil) to the left
905-909	Svanemøllen station, bus station to the left	2048	central bus terminal to the right
917	Carl Nielesensei to the left	2054	kadnuspladsen (main city square)
920	Carl Nielsensvej to the left	2009	brick buildings
940	njonøgade to the right	2070-2005	right turn to U.C. Andersons Devlayand
950-958	stop for red at Strandboulevarden	2110	ngnt turn to H.C. Andersens Boulevard
9/0	Arnusgade to the left	2122	Radnuspiadsen to the right
988	stop for red at Gunnar Nu Hansens Plads	2130-2148	parked at Kadnuspladesen

2149	central bus terminal to the right	3364-	Magasin (department store) to the left, parked
2157	crosing Studiestræde	3387-3389	Royal Theatre to the right
2186	"lions" (statues) at Jarmers Plads	3406	road crossing
2194	road crossing at Nørre/Vester Farimagsgade	3420	turn to Bredgade, GPS error
2207	tell briefs wells	3436	right turn to Sankt Annæs Plads
2217	tall Drick Walls	2449	Taldhadagada ta tha right
2223-2240	railway at Vesterport station to the left	3400	form to left "barbour area"
2247	parked at road crossing. Vesterport station	5480	Kvæsthusbroen
2237-2201	Trommesalshuen GPS error	3496	water to the right
2303-2310	crossing Vesterbrogade GPS error	3504-3512	lorry turns in front of "measurement car"
2319	Central railway staion West	3519-3528	turnaround, close to waterfront
2325	right turn to Istedgade	3553	"Harbour b ridge", ships
2340	crossing Helgolandsgade	3566	road crossing at Toldbodgade
2350	crossing Abel Cathrinesgade	3583	right turn to Toldbodgade
2369	road crossing at Gasværksvej	3601-3608	in front of Admiral Hotel
2380	left turn to Gasværksvej, GPS error		Amaliehaven to the right
2397	right turn to Halmtorvet	3623	left turn to Amalienborg (castle)
2420	road crossing at Skelbækgade	3641	Amaliegade to the right side
2428	left turn to Skelbækgade	3648	Western side
2455	roundabout at Fisketorvet, Dybbølsbro	3650	Frederiksgade to the right
2460	left turn to Ingerslevsgade	3661	exit
-2503	driving along railway (right dside)	30/0	exit, 101dbodgade
2503	right turn to Tistanagada	3080	aurus an Taldhadaada
2508 2515	alongoide the control rollway staion	2712	right turn to Ameliogado
2508-2515	stop for red at Bernstorffsgade	3712	road crossing at Esplanaden
2521-2540	right turn to Ved Glyntoteket	3739	left turn to Esplanaden
2573	Stoltenbergsgade to the right	3760	right turn to Grønningen
2580	crossing Niels Brocksgade	3784-4300	parked at Folke Bernadottes Alle
2300	driving along Otto Mønstedsgade, GPS error	4300	exit from parking area
2600	right turn to Hambrosgade	4314	left turn to Sølvgade
2612	right turn to Mitchellsgade, Polititorvet	4325	Nyboderhuse to the left
2618	right turn to Niels Brocksgade	4355-4380	stop for red, right turn
2632	right turn to Otto Mønstedsgade	4406	left turn to Webersgade
	"marble"- building to the right	4418	crossing Øster Søgade
2650	right turn to Hambrosgade, GPS error	4426	driving on Fredensbro (bridge)
2673	left turn to Bernstorrfgade	4442	crossing Blegdamsvej
2681	cargo railroad to the right		tall brick walls, Panum Institute to the left
2691	right turn to Kalvebod Brygge	4464-4468	right turn to Nørre Alle, very wide road
2700	Ingeniørhuset (engineer domicil) to the left	4501	street crossing at Universitetsparken
2721	right turn to "rame" towards Dybbølsbro	4527	crossing Jagtvej, driving along Lyngbyvej
2740	road crossing at Dybbøisbro staion	4548	Crossing Sejrøgade/Haraldsgae
2/30-2//0	Dybbølsbro, driving on bridge above rallway	4550	omøgade to the fight
2112	right turn to Ingerslevgade	4504-4570	under railway (viaduct) Ryparken motorwayi
2110	railroad to the right haire	4592	viaduct (road)
2826-2830	Tietgensbroen (bridge)	4618	viaduet (road)
2855-2865	stop for red at Bernstorffsgade	4647	"motorway shields to left and right"
2893	crossing H.C. Andersens Boulevard, turn to	4653	viaduct (road)
Stormgade	5	4671	viaduct (road)
2920	National Museum to the right, close to pillars		Gentofte sø (lake) to the right
	crossing (water) Frederiksholms Kanal	4705	exit E47 to Lyngby
2948	Thorvaldsens Museum to the right	4723	under bridge
2955	parked	4732	over bridge
2973	right turn to Christiansborg Slotsplads	4740-4750	over bridge
2980	driving past main entrance	4751	roundabout
2998	driving through gate		turn to Lyngby Hovedgade
3010	driving through gate, tall stone walls	4764	Vintappervej to the right
3027-3029	turn to Frederiksholm Kanal	4/83-4800	on bridge above railway
3040-3050	right turn to Marmorbroen ("marble bridge")	4808	left turn to Lyngby Hovedgade
3060	southern end of Ridebanen	4532	Jamhanavai ta tha laft
3084	statue to the left	4348	stop for red Magasin (warehouse) to the right
3003	eastern end	4800-4878	crossing Klampenborgyei
3103	northern side	4898	Toftebæksvei to the right
3125	exit from Ridebanen	4915	roundabout
3140	Ny Vestergade, GPS error	4932	Stades Krog to the right
3167	left turn to Vester Voldgade	4935	Lyngby church to the right
3190	GPS error	4941	right turn to Gammel Lundtoftevej
3194	left turn to Frederiksholms Kanal	4953	ILVA (warehouse) to the left
3212	construction debris	4959	driving between stone walls
3220	right turn to Bryghusgade	4967	right turn to Høstvej
3235	left trun to Vester Voldgade	4974	Peter Lunds vej
3254	water to the right	4989	left turn to Toftebæksvej
3266	under viaduct	5010-5019	stop for red, street crossing at Sorgenfrigårdsvej
3286	under Knippelsbro (bridge)	5033	Lyngvej to the right
3294 2220	water to the right	5051	Akademivej (DTU) to the right
3320	uriving along Niels Juelsgade	3031	right turn to Elektrovej (DTU)



Figure 3.4.1.1. Track lines for Area017.spc.



Figure 3.4.1.2. Detector temperature.

#### 3.4.2 Area051.spc

31	Start building 327, DTU		Station
53	paving stones	627	Kildevældsgade to the right
74	right turn to Asmussens vej	639	Nygaardsvej to the right
97	left turn to Akademivej	652-671	stop for red at Strandboulevarden
120	right turn to Toftegårdsvej	690-692	roadworks
153	Statoil tank to the right	700-713	stop for red at Gunner Nu Hansens
160	onto motorway ramp		Plads
174	on motorway	720	church to the right
201	motorway exit	727	roadworks
219	left turn to Jægersborgvej	763-771	stop for red at Trianglen
237	Ibstrupvænget to the right	780	to the right at Trianglen
241	road crossing at Smakkegårdsvej	792	Øster Alle to the right
276	Søndersøvej to the left	802	Red Cross building to the right
285	road crossing	821	hospital to the right
311	Vældegårdsvej to the left	829	turn to Rigshospitalet
318	Gentoftegade to the right		crosing paving stones
341	Maltegårdsvej to the left	847	main entrance at Rigshospitalet
358	Adolphsvej to the right	857-867	waits in line
371	Statoil tank to the left	870	turning around
374-380	stop f or red at Bernstorffsvej	895	left turn
392	Bernstorffsvej Station to the left	901	entrance 39, cyclotron
399	Ingeborgvej tot he right	923	paving stones
403	crossing railway	935-947	turning around
415	on railway bridge	955	road bump
422-438	stop for red at Cersonsvej	972	road bump
453	Vinager Alle to the left	1005	turn around
465	right turn to Strandvejen	1050	parked
486-488	road crossing	1067	turning around
500	Margrethevej to the right	1083	parked
517	Hellerupvej to the right	1134	turn to the right
528	Callisensvej to the right	1154-1156	exit, right turn to Blegdamsvej
550	Tuborg North to the left	1194	road crossing Fredensgade/
566	Gammel Vartov Vej		Tagensvej
602	road crossing at Svanemøllen	1200	Panum Institute to the right

1204	church to the right	2687	right turn across railway
1220	stop for red at Skt. Hans Torv	2702	right turn to Ingerslevsgade
1235	Skt. Hans Torv to ther ight	2744	Central Railway Station to the right
1247	Fælledgade/Nørrebrogade	2760	stof for red at Bernstorffsgade
1265	left turn to Nørrebrogade	2787	stop for red at H. C. Andersens
1284-1295	Dr. Louises Bridge		Boulevard
1320	right turn to Nørre Søgade	2807	crossing H. C. Andersens
1356	stop for red at Gyldenløwsgade		Boulevard
1381	left turn to Gyldenløwsgade	2822	National Museum to the right
1415	Jarmers Plads	2834	ston for red
1436	waits in line (buses)	2844-2851	crossing Frederiksholm Kanal
1357	right turn to Studiestræde	2860	Thoryaldsens Museum to the right
1467-1472	Palade to the left	2800	norvanuscus muscum to the fight
1407-1472	right turn along railroad	2873	Christianshara ato the right
1525	arossing Jermars Dlads	2873	status to the right
1555	right turn to Vostor Voldgodo	2019	statue to the light
1505	III tuill to vester volugade	2004	light turn, under gate
1587	n i busterininar to the right	2895	right turn under gate
1625	right turn to Stormgade	2909	under gate, tall stone walls
	right turn to H. C. Andersens	2921	paving stones to the right
1 ( - 1	Boulevard	2928	right turn to Frederiksholm Kanal
16/1	Rådhuspladsen to the right		paving stones
1690-1698	behind large lorry		parked
1706	stop for red at Rådhuspladsen		circling at Ridebanen
1740	Jarmers plads	3083	at Frederiksholm Kanal
1759	left turn to Vester Farimagsgade	3089	at Ny Vestergade
1804	Trommesalen, GPS error	3108	left turn to Vester Voldgade
1826	crossing Vesterbrogade	3161	turning at waterfront
1846	Right turn to Istedgade	3202	crossing Christians Brygge
1864	Helgolandsgade		brick buildings
1869	Abel Cathrinesgade	3227	road crossing at Ny Kongensgade
1881	Victoriagade to the left	3245	circling at Ridebanen
1903	left turn to Gasværksvej	3383	at Ny Vestergade
1915	right turn to Halmtorvet	3401	stop for red
1926	paving stones	3410	left turn to Vester Voldgade
1932	left turn to Skelbækgade	3438	left turn to Ny Kongensgade
1954	stop for red	3453	right turn to Frederiksholm Kanal
2000	turning at Fisketorvet	3481	right turn to Bryghusgade
2016	crossing railway	3564	left turn to Vester Voldgade
2045-2053	above railway	3511	left turn to Christians Brygge
2081	right turn to Ingerslevsgade (new	5011	water to the right
2001	asnhalt)	3530	under viaduct "glass" huildings
2112-2255	nausing at Ingerslevsgade	3560	under Knippelsbro
2112 2233	right turn across railway bridge	3560	crossing at Havnegade
2275	crossing Bernstorffsgade	5507	on Niels Juulsgade
2207	right turn to Ved Glyptoteket	3503	at Holmens Kanal
2303	arossing Niels Brocksgade	3533	At Holmen's Kanal Magazin to the left
2310	Delies station	2642	Devel Theotre to the right
2222	rolice station	2640	Royal Theate to the light
2332	night tuill	2049 2002 2077	toundabout at Kgs. Nytorv
2344	right turn	3663-3677	stop for red
2364	right turn to Otto Mønstedsgade	3680	at Bredgade
2375	right turn to Hambrosgade	3708	right turn to Skt. Annæ Plads
2.402	stop for red	3729	stop for red
2402	lett turn to Bernstorffsgade	<b>a-</b> (a)	lett turn to Toldbodgade
2406	roadwork	3760	Amaliehaven to the right
2428	right turn to Kalvebod Brygge		at Ioldbodgade
2449	stop for red	3810	right turn to Amaliegade
2460	ramp to Dybbølsbro Station	3824	right turn
	pausing		at waterfront, Esplanaden
2674	top of ramp	3862	stop for calibration check.



Figure 3.4.2.1. Track lines for file Area051.spc.

### 3.4.3 Area052.spc

	turning at Nordre Toldbod	485	on Langebro
62	crossing at Churchillparken	489-496	on Langebro above water
66	Kongeporten to the right		on Amager Boulevard
100	right turn to Grønningen	540	right turn to Artillerivej
139-150	left turn to Øster Voldgade	555-1079	pause at Q8-gasoline station
158	Nyboder to the left	1114	crossing Halfdansgade
189-221	stop for red Georg Brandes Plads	1147	Axel Heidesgade to the right
246	stop for red at Nørre Voldgade	1172	Dreschersgade to the right
262	Nørreport Station, stop for red	1190	left turn to Lossepladsvej
286	at Nørre Voldgade, along park	1225	Hekla Park
	Jarmers Plads	1279	left turn to Vejlands Alle
321	at Hammerichsgade	1321	stop for red at Center Boulevard
334	left turn to Vesterbrogade	1356	viaduct under metro
395-404	stop for red at Vesterbrogade	1363	crossing Fælleddiget
416	stop for red at Rådhuspladsen	1403	right turn to Englandsvej
440	right turn to H. C. Andersens	1425	Kålagervej to the right
	Boulevard	1454	roundabout at Vandtårnet
454	Tivoli to the right,	1474	stop for red at Sneserevej
	stop for red at Stormgade	1509	left turn to motorway
479	crossing road	1513	under viaduct, GPS error 18 s

1540	under bridge	3060	Bedfordvej to the right
1562	right turn to motorway exit	3089	crossing at Amagerbrogade
1615	Terminal 1, Kastrup Airport	3097	left turn to Amagerbrogade
1652	At Englandsvej	3111	large, brick houses
1668	Amager Landevej	3166	Sundbyvester Plads
1697	Merkur Alle to the right	3184	Højdevej to the right
1709	Løitegårdsvej to the right	3213	Øresundsvei
1727	Christen Kolds Alle to the right	3226	Lyongade to the right
1753	right turn to Tømmerupvei	3240	stop for red at Frankrigsgade
1784	Kirstinevei to the right	3288	Brysselsgade to the left
1811	left turn to Englandsvei	3322	Sverrigsgade to the left
1011	"garden market"	3337	crossing Holmbladsgade
1841	under the lanes GPS error 25 s	3348	Ved Sønderporten to the right
1892	St Magleby	3374	Markmandsgade to the right
1012	at Kirkevei	5574	crossing the water at Torvegade
1)12	bara fields	3417	Drinsessagade to the right
1067	small gardens to the right	3417	Christian Hayns Tory
1907	stop for red at Hartkornsvoi	3423	orossing Strandgada
1970	Stop for fed at markonisvej	2440	crossing Strangade
1998	Jægervej to the right	3403	crossing Knippeisoro
2026	right turn to Vestgrønningen	2406	right turn crossing Børsbroen
2053	left turn to Drogdensvej	3486	right turn to Holmens Kanal
2070	right turn to Færgevej	3532	left turn to Holmens Kanal
2077	Rønne Alle to the left	3556	Royal Theater to the right
2097-2123	Færgehavn (ferry harbour)		Kgs. Nytorv
2134	right turn to Strandlinien	3578	right turn to Skt. Annæ Plads
2146	on parking area	3616	left turn to Toldbodgade
2168	passing Strandlinien	3648	entrance to Amalienborg
2173	right turn to Rønne Alle		circling at Amalienborg
2190	to the right at Vestgrønningen		parked oputside Amalienborg
2230	stop for red	3672	Frederiksgade, Amalienborg
2254	right turn to Kongevejen, paving	3814	left turn to Toldbodgade
	stones	3857	right turn to Amaliegade
2276	Neels Torv	3873	left turn to Esplanaden
	left turn to Strandlinien	3879	Kongeporten to the left
2332	right turn to Rønne Alle	3901	right turn to Grønningen
2351	left turn to Vestgrønningen	3920	Nyboder to the left
	Søndre Strandvej	3951	left turn to Øster Voldgade
2408	Krudttårnsvej to the right	4022	right turn to Sølvgade
2469	right turn to St. Magleby Strandvej		Øster Farimagsgade
2500	left turn to Krudtværksvej/	4056	left turn to Webersgade
	Bachermindesvei		crossing Fredensbro
2544	right turn to Fælledvei		at Fredensgade
2580	farm, bare fields		at Tagensvei
2604	right turn to Søndergade	4098	Panum Institute to the left
2620	left turn to Møllegade	4137	right turn to Nørre Alle
2634	church to the right	4167	road crossing
2649	left turn to Englandsvei (F20)	4188	crossing Iagtvei
2700	under lanes GPS error 22 s	4100	at Lyngbyyei
2700	"garden market"	1226	crossing Seiragade/Haraldsgade
2732	stop for red at Tammarupyai	4220	under reilwey bridge Dynarken
2743	Ugandavei	4237	Halsinggrmatorygian (10)
2771	Drenderslav, Alle to the right	1200	neisingørmotorvejen (19)
2809	Biondersiev Ane to the fight	4388	exit motor way
2835	Visit Coundation the market	4400	under bridge
28/7	Ved Gærdet to the right	4423	roundabout at Vintapper Sø
2917	cnurch to the left	4450	graveyard stones
2953	vinkelhuse to the right	4465	crossing railway bridge
2968	roundabout	4467	right turn to Lyngby Hovedgade
• • • • •	Englandsvej	4488	paving stones, traffic jam
3000	left turn to Vejlands Alle	4573	Magasin to the right
3025	right turn to Vejlands Alle	4608	crossing Lyngby Torv

4667	roundabout	4768	Sorgenfrigårdsvej to the right
4682	Stades Krog to the right	4784	Akademivej to the right
4690	right turn to Gl. Lundtoftevej	4799	right turn to Elektrovej
4712	right turn to Høstvej	4822	parked at building 327, DTU
4737	left turn to Toftebæksvej		



Figure 3.4.3.1. Track lines for file Area052.spc.





Figure 3.4.4.1. Area015.spc (left) and Area017.spc (right): Air kerma rate map of Copenhagen roads, January 2004.



Figure 3.4.4.2. Area051.spc: Air kerma rate map of Copenhagen roads, April 2006.



Figure 3.4.4.3. Area052.spc: Air kerma rate map of Copenhagen roads, April 2006.

### 3.5 Fitting Components

#### 3.5.1 Area17cl.spc

The fitting components for file Area17cl.spc originate from a NASVD processing of the data set from channel 10 to channel 470. The data set contains spectrum drift of significance which shows as a spectrum drift signals as early as in spectral component S2. Only the first five spectral components and the mean spectrum, S0, are shown here. Due to the spectrum drift additional components containing further information on spectrum drift do exist; however, calculations were performed using five spectral components only. The file name for the fitting constants is Ar17clsc.txt.



Figure 3.5.1.1. Spectral components for Area17cl.spc. Component file name Ar17clsc.txt.

#### 3.5.2 Area051cl.spc

The fitting components for file Area051.spc originate from a NASVD processing of the data set from channel 10 to channel 470. The data set contains almost no spectrum drift signifying a very stable energy calibration. Only the first five spectral components and the mean spectrum, S0, are shown here. The file name for the fitting constants is Ar51clsc.txt.



Figure 3.5.2.1. Spectral components for file Area051cl.spc. Component file name Ar51clsc.txt.

#### 3.5.3 Area052.spc

The fitting components for file Area052.spc originate from a NASVD processing of the data set from channel 10 to channel 470 or from channel 20 to channel 470. The data set contains almost no spectrum drift signifying a very stable energy calibration. Only the first five spectral components and the mean spectrum, S0, are shown here. The file names for the fitting constants are Ar52sc.txt (channel 10 to channel 470) and Ar52sc20.txt (channel 20 to channel 470).





Figure 3.5.3.1. Spectral components for file Area052.spc. Component file name Ar52sc.txt.



Figure 3.5.3.2. Spectral components for file Area052.spc. Component file name Ar52sc20.txt.

#### **3.6** Spectra for Search for Lost Sources.

The original Danish urban data sets do not contain measurements on sources. To test the ability of the methods to find uncommon signals in a pool of data six different source signal spectra were added to the data sets. The amount of source signal is 62 additional counts. Each of the six spectra was added to specially selected spectra in the files Area052.spc. The spectra were chosen because of their differences in Th/U/K content and amount of scattered photons. Only one source signal were added for each investigation and it was added only once so as not to contribute to the shape of the spectral components or in the calculation of ASSS factors.



Figure 3.6.1. Spectra recorded with the Danish CGS systems at the Barents Rescue Exercise and in the laboratory (CsLab62).



Figure 3.6.2. Spectra recorded with the Danish CGS system at the Finsen Institute April 2006 in cooperation with Chief Physicist Holger J. Jensen.

### 3.7 Spectra with Added Source Signals

#### 3.7.1 Area052cl.spc: Original Measurements

Figure 3.7.1.1 shows eight measured spectra from file Area052cl.spc. To each of the spectra were added the spectra shown in Figure 3.6.1 and Figure 3.6.2. The spectra were chosen so as to represent different measurement geometries and different contents of natural radionuclides.



Figure 3.7.1.1. Selected spectra.

#### 3.7.2 Area052cl.spc with Added Source Signals

To limit the size of the report only one spectrum with added source signals is shown here. This spectrum is measurement No. 3466, the spectrum that has the lowest number of total counts of the eight spectra chosen.

Figure 3.7.2.1 shows that the source signal contributes very little to the total spectrum shape. Possibly, though, the signal from CsLab62 could be spotted by a skilled user as a possible source signal.



Figure 3.7.2.1. Example of added spectra to measurement No. 3466.

## 4 DANISH DATA TREATMENT WITH FSC

### 4.1 FSC Reproduction versus NASVD Reconstruction

In a previous initial test of the method (Ref. 6) showed that for a well stabilised system there is practically no difference between the NASVD fitting and FSC. A reproduced spectrum (FSC) looks exactly like a reconstructed spectrum (NASVD) if the same data set is used for calculation of the spectral components. The fitting constants  $c_1$  to  $c_x$  will then be the same as the corresponding amplitudes  $b_1$  to  $b_x$ . But what happens for poor calibrated system?

One of the purposes of the FSC method is to limit the amount of calculations and therefore only a few fitting constants are calculated. Under normal circumstances five fitting constants for each spectrum should be quite sufficient. If one includes more than five spectral components in the reconstruction, these additional spectral components are very likely to include source signals if sources were present during the survey. This means that the source signals can be fitted and only normal "error"-values will be calculated. The source can then be missed in the FSC error calculations. However, for a poor stabilised system it might be necessary to include more components as demonstrated in the following.

Area17cl.spc suffers from poor spectrum stabilisation meaning that the centroids "sail up and down" the energy axis during the measurement series. Fitting constants were calculated for this file by NASVD processing the data from channel 10 to channel 470 and using five of the created spectral components in the calculations. Two fitting iterations were made (confer next section).

The magnitudes of the fitting constants were compared to the magnitude of the amplitudes and differences were observed. NASVD calculates in principle as many spectral components as there are measurement channels and the same amount of sets of amplitudes. Additional information exists and can be applied by the user if the reconstruction with e.g. five components is not sufficiently good. FSC calculates only N sets of fitting constants from N spectral components. And no additional information exists. So how much information could one risk to lose? Figure 4.1.1 shows the cross plots of the FSC fitting constants to the amplitudes for Area17cl.spc. FSC constants c1 and b1 are the same, not much difference is obtained for the pairs  $c_2$  and  $b_2$  and  $c_3$  and  $b_3$ , either. For the following pairs, however, the difference shows. This tells that the FSC reproduction using five spectral components only will be slightly inferior to the NASVD reproduction with five spectral components. But the result is still very good. Please notice also the postulate above than under normal circumstances five spectral components are enough. Here are demonstrated errors using five components only and the errors are small both for four and five components. Using only four spectral components and four sets of FSC constants is therefore also reasonable under normal circumstances.

FSC has the advantage that a set of spectral components can be created once and then reused on future measurements with satisfactorily results (confer Section 4.3.3). The spectral components with the FSC method in this report originate from NASVD processed data. In principle it is also possible to obtain a set of standard spectra to be used with FSC without using NASVD.



Figure 4.1.1. Cross plots of FSC fitting constants and NASVD amplitudes.

### 4.2 Iterations

In Section 3.3.3 is described the mathematics for the FSC method. The FSC program used can perform a number of iterations according to the users' choice. For each iteration a new set of weight factors ( $w_{i,j}$  is selected as  $1/var(n_{i,j})$ ) is calculated. But how many iterations are in fact necessary?

The data from file Area17cl.spc have been fitted with five spectral components from channel 10 to channel 470 using one, two, three, four and five iterations and five sets of fitting constants. In the first iteration, the weight factor is calculated from the mean spectrum, i.e. spectral component No. 0. This is of course not optimal for all spectra in the file. In the second fitting the weight factors for a spectrum is calculated from the reproduced spectrum from the first iteration, et cetera.

Table 4.2.1 shows the average fitting constants for one to five iterations. The differences are very small and the average starts to fluctuate very quickly. No more than two iterations are necessary. To iterate additional times does not improve the result. The values for each individual constant for each number of iterations are in fact quite similar. Figure 4.2.1 shows the c1 values for one iteration from which have been subtracted the values for two and five iterations, respectively. Figure 4.2.2 shows the corresponding c3 difference values.

There is not much to be gained from more than one iteration. However, a few differences are found, e.g. around measurement No. 3395 at Øster Søgade driving along the waterfront (canal) and around measurement No. 4449 driving around The Panum Institute (large brick walls).

jive spectrui components in jite Areu17ci.spc.								
No. Iterations	<b>c</b> 1	c2	c3	c4	c5			
1	0.0000	0.0000	0.0000	0.0000	0.0000			
2	0.0001	-0.0002	0.0002	-0.0104	-0.0036			
3	0.0001	-0.0008	-0.0002	-0.0039	-0.0029			
4	0.0001	-0.0007	-0.0001	-0.0058	-0.0030			
5	0.0001	-0.0008	-0.0002	-0.0046	-0.0030			

 Table 4.2.1. Average fitting constants for fitting of spectra with

 five spectral components in file Area17cl.spc.



Figure 4.2.1. Fitting constant  $c_1$ -values. Values for 2 and 5 iterations subtracted from values for 1 iteration.



Figure 4.2.2. Fitting constant c3-values. Values for 2 and 5 iterations subtracted from values for 1 iteration.

To illustrate the order of magnitude of the FSC constants the  $c_1$ -values and  $c_3$ -values are shown for one and five iterations respectively. Spectral component  $s_3$  contains a potassium signal as its main feature.



Figure 4.2.3. Fitting constants c<sub>1</sub>- and c<sub>3</sub>-values. Results for one iteration.



Figure 4.2.4. Fitting constants c<sub>1</sub>- and c<sub>3</sub>-values. Results for five iterations.

#### 4.3 FSC for File Area052.spc

The FSC method was tested on the file Area052.spc with four different set of fitting constants. The fitting constants were calculated from the file itself or from other CGS data files. Two sets of fitting constants were calculated for the file itself: a set of constants using the standard (standard for DTU and DEMA) processing limits from channel 20 to channel 470 and a set of constants using a lower processing limit of 10 instead of 20. Another set of fitting constants were calculated from a file recorded earlier the same day, Area051.spc. This file was recorded approximately 1 hour after rainfall and the spectral components show a radon signal which is not found in file Area052.spc. Finally a set of constants were calculated from a 2-year old file, Area017cl.spc. This data file is of pooor quality with respect to spectrum stabilisation.

#### 4.3.1 Count Rates for File Area052.spc

Results, however, does not necessarily indicate how good a method is if one does not know the "initial" material. Therefore plots of gross count rates in the analysed channel windows are presented here together with the count rates for the natural radionuclide windows. The file does not contain sources and for all low energy windows the natural radionuclide composition shows through.

A description of the survey is found in Section 3.4.4. The flat curve between approx. 500 and 1000 is due to a break (statistical fluctuations at a gasoline station). The peak at approx. 1500 is a result of driving under a viaduct. Nos. 1600 to 1630, approx., is Kastrup airport. In general, the highest count rates were found at Amalienborg (3650) and Lyngby Hovedgade (last part of the file) and were caused by pavings of paving stones.



Figure 4.3.1.1. Count rates in low energy windows used with FSC, file Area052.spc.



Figure 4.3.1.2. Count rates in natural radionuclide windows used with FSC, file Area052.spc.

#### 4.3.2 FSC using Fitting Constants from File Area052.spc

If all necessary spectral components have been included in the calculation of the fitting constants the average of the fitting constants should be zero. The average fitting constants for Area052.spc were very close to zero, Table 4.3.2.1.

<i>Table 4.3.2.1. Ave</i>	rage FSC	constants	s calculate	ed from fil	le Area052	. <i>S</i> ]
Component file	<b>c</b> 1	c2	c3	c4	c5	
Ar52sc.txt	0.000	0.000	-0.002	0.000	0.000	

T 11 4 2 2 1 4 Daa 1 1 / 10 nc.

A set of windows (defined in Section 3.1.1.4) was analysed for errors. The average errors were only slightly above what to expect from a  $\chi^2$  test (Expected, Table 4.3.2.1). Without going into minor detail analysis of each possible high value (or low value) error, the Figures 4.3.2.1 to 4.3.2.3 show no real indication of anything beyond the ordinary, i.e. a possible source signal. - Amalienborg, though, should probably be checked for natural anomalies.

The three plots shown are for a low energy window, a caesium window and a cobalt window. It is noticed, that the errors from the FSC calculations does not follow the count rate pattern for the natural radionuclides.

The plots are representative of the normal variations in a city the size of Copenhagen. One might choose to fix a 90% confidence level as a standard value for a possible source signal – or one might set the level based on source measurement. In Section 6 the FSC method will be used on the same data set to which source signals have been added.

Component file	0	20-40	48-65	50-70	55-72	100-120	180-220
Ar52sc.txt	Average	20.483	17.741	20.644	17.687	20.703	40.881
	Expected	20.3	17.3	20.3	17.3	20.3	40.3

Table 4.3.2.2. Average errors and expected errors for fitting of spectra in file Area052.spc.



Figure 4.3.2.1. Low energy window errors.



<sup>137</sup>Cs window errors. Figure 4.3.2.2.



#### 4.3.3 FSC using Fitting Constants from File Area051cl.spc

The file Area051cl.spc were made on the very same day but the radon content in the air was slightly different. Table 4.3.3.1 shows that the fit is not perfect. The average values of the fitting constants are not zero. So, what will the consequences be considering the calculated errors? Again three plots are shown: the low energy window, the caesium window and the cobalt window. And again no measurement stands out and presents itself as a possible source signal. The plots looks very much the same as had the analysed data file been used for the FSC constants calculations. In general the errors are 0.1-0.15 higher, Table 4.3.3.2.

Table 4.3.3.1. Average FSC constants calculated from file Area051cl.spc.						
Component file	c1	c2	c3	c4	c5	
Ar51clsc.txt	-0.499	0.327	0.009	-0.341	0.053	





Figure 4.3.3.1. Low energy window errors.

Delt	ta²	Cope	enhagen su	irvey 7 Ap	oril 2006 A	rea052.s	pc: FSC e	errors		
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0.	0 50	0 1000	1500	2000	2500	3000	3500	4000	Spc. No.	5000

Figure 4.3.3.2. <sup>137</sup>Cs window errors.



Figure 4.3.3.3. <sup>60</sup>Co window errors.

Table 4.3.3.2. Average errors and expected errors for fitting of spectra in file Area052.spc.

Component file		20-40	48-65	50-70	55-72	100-120	180-220
Ar51clsc.txt	Average	20.584	17.829	20.800	17.822	20.837	41.126
	Expected	20.3	17.3	20.3	17.3	20.3	40.3

#### 4.3.4 FSC using Fitting Constants from File Area017cl.spc

File Area017cl.spc contains a large, spectrum drift signal in spectral component 2 that is not seen in the files Area052.spc or Area051cl.spc. When the file Area052.spc is fitted with the constants originating from this poor data file, information is lost. The average fitting constants are far from zero indicating, that more spectral components would be needed to obtain a proper fit. But how bad are the results? Table 4.3.4.2 shows the average errors that are seen to increase further compared to the average errors from Area051cl.spc – however, the errors for the caesium window and the cobalt window have decreased. Again, the error plots do not signify a source signal present somewhere in the surroundings.

<i>1 able 4.3.4.1. Ave</i>	erage FSC	constants	s calculate	ed from fi	le Area017
Component file	c1	c2	c3	c4	c5
Ar17clsc.txt	0.402	0.853	0.202	0.276	-0.342

Table 4.3.4.1. Average FSC constants calculated from file Area017cl.spc.

Table	4.3.4.2. Aver	rage errors	and expected	l errors for	fitting of	spectra in	file Area052.spc.
10000	1.0.1.2.11/0	age errors			Juning of	speece a vir	<i>,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,</i>

10000 1.5.1.2.1170	age errors	errer enp		, s jei jui	ing of sp		
Component file		20-40	48-65	50-70	55-72	100-120	180-220
Ar17clsc.txt	Average	20.761	17.921	20.882	17.863	20.601	40.820
	Expected	20.3	17.3	20.3	17.3	20.3	40.3



Figure 4.3.4.1. Low energy window errors.



Figure 4.3.4.2. <sup>137</sup>Cs window errors.



Figure 4.3.4.3. <sup>60</sup>Co window errors.

#### 4.3.5 FSC using Fitting Constants from File Area052.spc: New NASVD Limits

The three previous fits were made with the lower NASVD processing limit very close to the cut-off detection limit which is, for the Danish system, approximately at the limit where a <sup>241</sup>Am may or may not be detected. When a very low limit is used one should be cautious not to fit too much of the "cut-off" energy tailing at the lowest energies. Will the results then be improved if the NASVD lower level is increased from channel 10 to channel 20? Fittings similar to those of the three previous sections were made using a lower limit of 20. The resulting fitting constants are shown in Table 4.3.5.1. When fitting with a poor data quality file the average fitting constants do get closer to zero indicating a better fit. For the good quality data sets, no general tendency is seen. So what happens with the results? Table 4.3.5.2 shows that the average errors do decrease especially for the very low energy window (scattered radiation). In fact, the fitting for this window seemingly is better then what one should expect. A possible explanation for this has not yet been found.

	0			5	9
Component file	c1	c2	c3	c4	c5
Ar52sc20.txt	0.000	0.000	-0.001	0.000	0.001
Ar51clsc2.txt	-0.411	-0.381	-0.043	0.025	0.019
Ar17clsc2.txt	0.347	0.743	0.161	0.271	-0.317

*Table 4.3.5.1. Average FSC constants calculated from file Area017cl.spc.* 

Tuble 4.5.5.2. Average errors and expected errors for fitting of spectra in f								
Component file		20-40	48-65	50-70	55-72	100-120	180-220	
Ar52sc20.txt	Average	20.071	17.673	20.565	17.625	20.628	40.719	
Ar51clsc2.txt	Average	20.256	17.747	20.723	17.747	20.780	40.964	
Ar17clsc2.txt	Average	20.344	17.944	20.902	17.894	20.647	41.015	
	Expected	20.3	17.3	20.3	17.3	20.3	40.3	

Table 4.3.5.2. Average errors and expected errors for fitting of spectra in file Area052.spc.

#### 4.3.6 Comparison of FSC Results for File Area052.spc

It has been shown that it is possible to remove constributions from the natural radionuclides to an error level approximately the same size as one would achieve by a  $\chi^2$  test. It has also been shown that it is possible to fit a data set using information from other data sets recorded during different circumstances: radon remains, slight snow cover and rain.

Changing the data processing limit not to include the lowermost channels slightly improve the reults. Figure 4.3.6.1 shows the distribution of FSC errors for the caesium window. Apart from the very few, large errors (attributed to Amalienborg) the distribution of errors is close to a 50-50 distribution around the expected mean value.



Figure 4.3.6.1. FSC errors in the caesium window for three different fitting files.

### 5 DANISH AREA SPECIFIC STRIPPING OF FILE AREA052.SPC

Although FSC was the proposed Danish analysis tool for the CGS project it was considered worth the effort to also test the method of ASSS on the same data. ASSS was first used by Danish CGS teams at the Barents Rescue exercise, and the method's ability to find weak source signals have previously been demonstrated.

FSC performs analysis on the entire spectrum whereas ASSS only uses window count rates.

Three sets of ASSS factors were calculated for the same files and same windows that were used in Section 4. Table 5.1.1 shows the ASSS factors. The different survey paths and the the different radionuclide compositions show as variations in A, B and C for the same windows. Table 5.1.2 shows the average measured count rate that should be compared to the stripped results presented in Table 5.1.3.

Are052.spc includes a drive in the courtyard of Amalienborg and rush hour traffic driving at Lyngby Hovedgade (paving stones). ASSS is not able to strip away the large contribution of

scattered photons originating from those paths. The result is positive count rates of approx. 2 cps in all windows.

Area051.spc includes post-rainfall signals and no measurements from the Island Amager where the measurement geometry is somewhat different from the main part of Copenhagen. Despite the spectrum drift in Area17cl.spc the average fit is remarkably good.

		1 2	1		0		
File		20-40	48-65	50-70	55-72	100-120	180-220
Area052.spc	А	6.960	2.260	2.388	1.814	0.923	0.530
	В	8.141	2.487	2.521	1.935	1.034	0.598
	С	7.023	1.777	1.832	1.378	0.622	0.487
Area51cl.spc	А	8.419	2.613	2.746	2.037	1.049	0.526
	В	11.190	2.893	2.947	2.249	0.954	0.574
	С	6.429	1.695	1.744	1.322	0.628	0.498
Area17cl.spc	А	9.385	2.809	2.904	2.246	1.165	0.581
	В	11.786	3.244	3.324	2.425	1.273	0.652
	С	6.026	1.609	1.660	1.260	0.588	0.485

Table 5.1.1. Area Specific Spectrum Stripping Factors.

Table 5.1.2. Average count rates for spectra in file Area052.spc.

222-253	267-299	386-449	20-40	48-65	50-70	55-72	100-120	180-220
68.662	11.438	12.584	665.295	181.119	186.867	141.574	67.909	48.279

*Table 5.1.3. Average remaining count rates for area specific spectrum stripping of Area052.spc.* 

File	20-40	48-65	50-70	55-72	100-120	100-120	180-220
						4-win.	
Area052.spc	2.400	2.233	2.217	1.981	1.725		11.251
Area51cl.spc	-10.099	-1.203	-1.165	-0.569	0.706	4.426	11.030
Area17cl.spc	-1.391	-1.792	-1.693	-0.953	-1.709		10.115

The major difference between FSC and ASSS is seen when comparing the Figures 5.1.3.1-5.1.3.3 to the earlier FSC figures from Section 3. ASSS performs improper stripping that follows the count rates for natural radionuclides. If one wants to investigate if e.g. a <sup>137</sup>Cs or <sup>60</sup>Co signal is present a comparison with the natural radionuclides window count rates is necessary. This is not the case for the FSC method.

cps		Copenh	agen sur	vey 7 Ap	ril 2006 A	rea052.s	pc: ASSS	6 Count r	ates	
400										
300 ·		— ASSS	5 20-40 -							
200 -								11.		
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-100	<b>G</b> (* <b>178</b> )	at naik a a		00 20	0	od i ind	<u>0</u> 11. i		00 45	<u>50</u> 00
200	1' 'I	4	ար ուս	•	11.	''	11		1.64.1	י ודיי
-200 .					1			11.4		
-300 ·									-	
-400 ·	li -								Spc	. No

Figure 5.1.3.1. Low energy window errors. ASSS constants from file Area052.spc.

cps	Copenhagen survey 7 April 2006 Area052.spc: ASSS 0	Count rates
30	- ASSS 100-120	
20		
10		
0	dan menyara isi alam kadamata dat distanti 🗄 tilan seri	1
-10	A SAMA AN UMPANYA IN A REPORT OF A SAMA PART OF A S	
-30		
-40		Spc. No.

Figure 5.1.3.2. <sup>137</sup>Cs window errors. ASSS constants from file Area052.spc.

cps	-	Coper	ihagen su	rvey 7 Ap	oril 2006 A	Area052.s	spc: ASS	S Count r	ates	
30 -		ASSS 18	0-220							
25 -			<u> </u>							din 🗌
20 -	ريتناز رالا		il. i	I I	li .d u	ال ال ا		jiji, i		
10 -	1	ין ריארי די	म् भूमिल्युः अ		. In the	וייזן די	ni Likili	1. fini <sup>1</sup>	. I hud	
5 -	de la la de la	n han ha	tr fa plife	ili dan da	and the second	a ia tha <sup>b</sup> a		17 <b>- 1</b> 14, 10	in i i an	AL. MI
0 -				- 1	00 05	1111 00 00	00 05	00 40	00 45	
-5 -10 -	и)		15	UU 2U	00 25	00 30	00 30	uu• 40	Spc	. No.

Figure 5.1.3.3. <sup>60</sup>Co window errors. ASSS constants from file Area052.spc.

Figure 5.1.3.4 shows the ASSS stripped count rate distribution for ASSS factors calculated for the file Area052.spc.

CDS		Conor	hagon cu		nil 2006	Aroa052		S Count r	ator	
40 -	1	Copen	inayen su	livey / A	111 2000 1		spc. A00		ales	
30 -			100-120							
20		1000	100-120							
20 -									_	
10 -										
0 -		-								
-10		<del>0</del> 10	00 15	00 20	00 25	00 30	00 35	00 40	00 45	<u>00 50</u> 00
-20 -	1									
-30 -										
40									Spc	. No.

Figure 5.1.3.4. ASSS errors in the caesium window for fitting with Ar52sc.txt.

So far no source signals have been present in the data sets. In order to find out which method would be preferable to use source signals were added and the results for the two methods are compared in Section 6.

### 6 DANISH RESULTS FOR FILE AREA052.SPC WITH ADDED SOURCE SIGNALS

To each of the eight chosen files from file Area052.spc (Section 3.7.1) were added six different spectra containing source signals (Section 3.6).

Two of the spectra are <sup>137</sup>Cs spectra, CsPeak62 is an environmental spectrum whereas CsLab62 is a laboratory made spectrum with only few scattered photons. CoScat were made from measurements on a <sup>60</sup>Co source in containment and does not contain fulle energy signals as opposed to Bmb60Co. 15Ox62 and 99Tc62 are typical spectra associated with medical applications.

Each spectrum was only added to one measurement in the file Area052.spc at a time and only once, i.e. a total of 48 data files were analysed.

The FSC method and the ASSS methods both were tested using fitting constants and ASSS factors calculated from the file itself. (FSC component file Ar52clsc20.txt.) The FSC fitting constants are shown in Figure 6.1.



Figure 6.1. FSC fitting constants for eight spectra in file Area052.spc.

The results are presented graphically superimposed on FSC error plots and ASSS stripped count rate plots for the original data set containing no source signals.



Figure 6.2. FSC errors for low energy window channel 20 to channel 30.



Figure 6.3. ASSS stripped count rates for low energy window channel 20 to channel 30.

The following observations were made:

#### <u>99Tc62</u>

This spectrum goes undetected with the ASSS method and the FSC method both. The peak in channel 23 fits too well with the normal spectrum shape at the low energies and FSC manages to fit the spectrum. ASSS actually shows slightly lower error values than before the addition of this spectrum. The introduction of a new window from channel 10 to channel 20 did not identify the source either.



Figure 6.4. FSC errors for low energy window channel 20 to channel 40.



Figure 6.5. ASSS stripped count rates for low energy window channel 20 to channel 40.

#### <u>150x62</u>

The source signal is observed for spectrum Nos. 2282, 3644, and 4335 for ASSS in window 48-65 and for spectrum 4335 in window 500-70, also for ASSS only. Otherwise the source is undetected. The FSC method showed that for only one measurement, No. 1625, did the source signal rise above the general error fluctuations. For the ASSS method four measurements indicated a possible source. (One notices the peaks from Amamlienborg around the measurement No. 3540 that would also lead to suspisions of a possible source.)

An interesting detail is that ASSS for three of the measurements show significant low count rates in the cobalt window. A much too strong stripping also indicates a possible source. A source signal of twice the added amount would have been spotted for all measurements except for measurement No. 3607 using the FSC method.



Figure 6.6. FSC errors for low energy window channel 48 to channel 65.



Figure 6.7. ASSS stripped count rates for low energy window channel 48 to channel 65.

#### CoScat

The low energy peak of this spectrum is not spotted by any of the two methods. In the windows 48-65, 50-70, and 55-72, however, the source is seen for all eight measurements. Again ASSS shows strong negative stripped count rates in the cobalt window indicating that something is out of the ordinary for those measurements.

#### Bmb60Co

This spectrum only shows in the cobalt window for both methods. FSC only presents two significant results. ASSS presents three significant results and two "suspicious" results. Both methods find the signal in measurement No. 2282. FSC easily spots the signal in measurement No. 3466 (bridge) whereas ASSS do not.



Figure 6.8. FSC errors for low energy window channel 50 to channel 70.



Figure 6.9. ASSS stripped count rates for low energy window channel 50 to channel 70.

#### CsPeak62

The source signal from this source does not show in the low energy windows and only the FSC method is able to find it. Two measurements, No. 1625 (airport) and No. 3466 (bridge) where the count rates are low are identified as containing source signals and one measurement, No. 3109, is "suspicious".

The reason for not finding the source signals using ASSS has not been explained. That the FSC method is not able to find the signals in all the eight spectra is explained by the ratio of the low energy photons to the full energy peak photons. For measurements that have many counts in the 608 keV peak compared to the number of scattered photons in the low energy spectrum region, the measurements and the source signals resemble each other and most of the source signal is fitted as an expected radon signal.

#### CsLab62.

This laboratory made spectrum contains very few scattered photons but a distinct full energy peak. The signal only shows in the dedicated caesium window. The FSC method readily identifies three measurements, Nos. 1625, 3109, and 3466. The ASSS method finds almost all eight signales, the results for measurements Nos. 3466 and 3907 are slightly dubious.



Figure 6.10. FSC errors for low energy window channel 55 to channel 72.



Figure 6.11. ASSS stripped count rates for low energy window channel 55 to channel 72.



Figure 6.12. FSC errors for low energy window channel 78 to channel 93.



Figure 6.13. ASSS stripped count rates for low energy window channel 78 to channel 93.



Figure 6.14. FSC errors for caesium window channel 100 to channel 120.



Figure 6.15. ASSS stripped count rates caesium window channel 100 to channel 120.



Figure 6.16. FSC errors for cobalt window channel 180 to channel 220.



Figure 6.17. ASSS stripped count rates caesium window channel 180 to channel 220.

In general the following comments can be made:

When a source is found by the FSC method, the evidence is stronger than when a source is found by the ASSS method.

ASSS finds more signals but introduces also a lot of "false" source possibilites that could take a long time to investigate. This is caused by insufficient stripping of the natural radionuclides.

Data processing by the ASSS method is beyond doubt easier to do than data processing by the FSC method because the ASSS method only require the gross count rates for the measured spectra whereas the FSC method require that the user is able to extract a series of spectral shapes. ASSS therefore could be used also with simpler equipment as e.g. GM counters. The ASSS method may be easier to apply but the interpretation of the results are more difficult. Some experience in comparison of natural radionuclide count rates to stripped count rates is needed. Another issue, that has not been discussed in this report but elsewhere (Ref.3, 4) is the possibility of obtaining very erroneous ASSS factors if measurements containing strong "high" energy source signals that give counts in the potassium windows (and possibly above if pile up), e.g. <sup>60</sup>Co, are not removed from the data sets before the ASSS factors are calculated.

## 7 FINNISH CGS MEASUREMENTS

### 7.1 The Finnish CGS System

The Finnish mobile laboratory (SONNI - Sophisticated On-Site Nuclide Identification system) has two electrically cooled coaxial HPGe detectors. Cooler units are mounted in a passively stabilized cradle, which counteracts the tilting of the vehicle while it is moving. The in-situ measurement crystal is mounted on the ceiling of the main operations section of the vehicle away from the bulk of the equipment. The lead shield of the sample measurement detector is securely fastened to the floor of the vehicle and the detector faces downwards. For added redundancy, the detector mountings are designed so that in case of a break down, the remaining detector can be installed in either position; thus, the function with the highest priority can be maintained.

SONNI has three NaI(Tl) scintillation detectors. Two large detectors (5" x 4") are mounted on the opposite walls of the main operation area facing the sides of the vehicle. Steel shields of 15 mm around the detectors create fields of view opening outwards. This type of configuration enables good detection and localization of radiation sources. One small detector (2" x 2") is mounted inside a 15 mm thick steel tube opening in the direction of travel. This type of collimation makes it possible to make a spatial scan of the incident site from a distance. In addition, it gives a capability to pinpoint target vehicles among the traffic. Timestamped measurements can be used to identify the source of the radiation or the suspect vehicle from the simultaneous video recording.



Figure 7.1.1. Interior of Sonni. The two main NaI detectors can be seen on either side in the back. The HPGe detector is barely visible in the top of the picture.

#### 7.2 The LINSSI Database

The Finnish data is collected to a relational database LINSSI

<http://linssi.hut.fi/radphys/linssi/> running under MySQL. This database incorporates all relevant data, including raw spectrum data, positional data and analysis results. The general table layout of LINSSI is depicted in Figure 7.2.1.



Figure 7.2.1. Table layout of the LINSSI database. For a complete description of LINSSI and all its fields please see <a href="http://linssi.hut.fi/radphys/linssi/">http://linssi.hut.fi/radphys/linssi/</a>.

# 7.3 XML-Format for Radiological Messages in In-Situ Measurements with Sonni

Data transfer between LINSSI databases in SONNI and at the STUK headquarters, is done through an XML format. This format is also used in this UGS project as an interim data format for transfer between the Danish CGS format and the LINSSI database.

A script has already been written for transferring the Danish data into this XML format.

#### 7.3.1 Message Format - Example

```
<?xml version="1.0"?>
<!DOCTYPE SONNI SYSTEM "insituSONNI.xsd">
<message>
<defaultParams block="spatialData">
              <param pos="0" format="UTC">time</param>
<param pos="1" unit="deg" datum="WGS84">xCoodinate</param>
              contain pos 1 unit = "deg" datum = "WGS84">yCoodinate /param
contain pos = "3" unit = "m">altitude /param>
              <param pos="4" unit="deg">heading</param>
</defaultParams>
<defaultParams block="peakData">
              <param pos="0">nuclideId</param>
              <param pos="1" unit="keV">lineEnergy</param>
              <param pos="2">significance</param>
              <param pos="3" unit="cnts">peakArea</param>
              <param pos="4" unit="cnts">uncPeakArea</param>
</defaultParams>
<defaultParams block="roiData">
              <param pos="0">roiId</param>
              <param pos="1" unit="chn">ROIstart</param>
              <param pos="2" unit="chn">ROIend</param>
              <param pos="3" unit="cnts">ROIarea</param>
</defaultParams>
<stationId>SONNI</stationId>
<idMessage>297</idMessage>
<hypothesisRiskLevel>1E-06</hypothesisRiskLevel>
<measurement>
              <idMeas>4208</idMeas>
              <acqStart>20060310101244</acqStart>
              <detectorName>L</detectorName>
              veTime>4.9</liveTime>
              <spatialData>
                   <parameters>
                             <param pos="0" format="UTC">time</param>
                             <param pos="1" unit="deg" datum="WGS84">xCoodinate</param>
                             <param pos="2" unit="deg" datum="WGS84">yCoodinate</param>
                             <param pos="3" unit="m">altitude</param>
                             <param pos="4" unit="deg">heading</param>
                             </parameters>
                             <values>
                             20060310101249 25.0159 60.12456 50 0.6
                             ...Next position during measurement..
                             </values>
              </spatialData>
```

<peakData>

</measurement> </message>

-	<parameters></parameters>				
	1	<param po<="" td=""/> <td>s="0"&gt;nuclideI</td> <td>d</td> <td></td>	s="0">nuclideI	d	
		<pre>contraction </pre>	s = "l" unit="ke	V">lineEnergv </td <td>baram&gt;</td>	baram>
		<pre>raram po</pre>	s="2">signific	ance	
		<pre>charam po</pre>	s = "3" unit = "cr	nts">neakArea </td <td>/naram&gt;</td>	/naram>
		<pre>&gt;param po</pre>	s = "4" unit = "ci	its">uncPeakAre	pa:an pa
		parampo	5 / 11/11/ 01		, pur univ
	<values></values>				
	Am-241	59.5	-0.232	-32.067	29.043
	Tc-99m	140.5	0.432	127.078	61.861
	Ra-226	186.2	0.431	135.392	66.076
	Ir-192	316.5	0.089	21.823	51.669
	I-131	364.5	0.050	12.074	50.424
	Ir-192h	468 1	0.345	75 534	46 084
	Cs-137	661 7	2,931	652.019	46 801
	Co-60	1173 2	0.212	10 977	10 889
	Co-60b	1332.5	-0 187	-9 204	10.002
	K-40	1460 8	0.686	33 673	10.373
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Fields used with SONNI are written in **bold.** Required parameter definitions can be written in <defaultParams>-blocks or within the corresponding <data>-block in /parameters>-block. A minimum of one <Data>-block per message is required. The <spectralData>-block is not used in automated messaging from SONNI but can be used with other applications on demand. Spectrum is given within the <spectrum>-tags as counts per each channel, separated with one or many white space characters.

### 7.4 CGS Analysis Tools

#### 7.4.1 Standard Software

Sonni is equipped with the Unisampo-Shaman (USS) spectrum analysis package. Unisampo is capable of mobile in-situ spectrum acquisition and real-time analysis. It also is equipped with waterfall and roi area display functionalities for data visualisation in the vehicle. A picture of the Unisampo waterfall spectrum is shown in Fig. 7.4.1.1.

The USS package can also be used for in depth analysis of interesting spectrums. USS is specialised on HPGe analysis, but Unisampo can also handle NaI spectra.



Figure.7.4.1.1. Unisampo Waterfall plot. The thin yellow streak just above the crosshair is from a <sup>99m</sup>Tc source detected during the 2005 Athletics World Championship (Radiology patient outside a hospital).

#### 7.4.2 In-house data Processing Methods

Measured spectra are analyzed in real time with a script using a simple summation algorithm over predefined areas of interest. The analysis assumes that the spectrum contains peaks of the predefined nuclides and tests this hypothesis by calculating the peak significance for each nuclide. The peak significance *S* is defined as:

$$S = \frac{A}{L_c(\alpha)} = \frac{A}{k_\alpha D(A)}$$
(7.4.2.1)

where A is peak area, D(A), the standard deviation of the peak area,  $L_C$  Currie's decision limit (Ref. 11) and  $k_a$  sets the risk level of detecting false positives in terms of the Gaussian abscissa. With  $k_a = 4.753$ , S>1 once in a million measurements (type I error risk  $\alpha = 10^{-6}$ ). Exceeding the decision limit S=1 triggers an automatic alarm.

The summation algorithm is presented in Figure 7.4.2.1. The baseline *B* is calculated from both sides of the assumed peak by summing up the counts in both baseline calculation areas  $B_1$  and  $B_2$  and by scaling with the number of channels under the peak (*W*) and the baseline (2*n*):

$$B = \frac{B_1 + B_2}{2n} W, \qquad (7.4.2.2)$$

The peak area is then calculated simply with equation:

$$A = \frac{C - B}{g},\tag{7.4.2.3}$$

where C is the total counts in the peak calculation area. If the peak calculation area does not span over the whole Gaussian peak, the total counts in a peak is gained by scaling with the area correction parameter g.



Figure 7.4.2.1. Gaussian peak and the summation algorithm used for hypothesis testing. All parameters are given in units of FWHM. Parameters used for NaI(Tl) spectra are Peak Width = 1.2, Baseline Width = 0.6, Baseline Distance = 1.2 and g = 0.842.

The variance of the peak area  $D^2(A)$  is then estimated with:

$$D^{2}(A) = \frac{1}{g^{2}} \left| A + B \left( 1 + \frac{W}{2n} \right) \right|$$
(7.4.2.4)

All calculations are done in channels. The statistical behaviour of this method is described in detail in reference (Ref. 12).

### 7.5 Finnish Data Sets

The main Finnish dataset to be used in this project is the more than 25000 NaI spectra measured in the Helsinki region during the Athletics World Championship in 2005. During a period of two weeks, Sonni made daily routes around the Helsinki Stadium and the Otaniemi area, where the athletes had their lodgings. These routes are shown with thick blue lines in the maps in figures 7.5 and 7.6. Additionally Sonni measured the area along the Marathon route before the event. This route is shown in green in fig 7.6. The dataset also includes measurements made during transition between the two areas, and to or from the headquarters in eastern Helsinki.

All mobile measurements in this dataset are 5 sec long. The spectrums consist of 1024 channels. Sonni is equipped with a climate control system and the energy calibration was adjusted manually several times each day, to counteract the effects of temperature drift. The resolution of the NaI detectors is approximately 8% when driving in the field.

Furthermore, another dataset with signals from artificial radionuclides is available as test and comparison data. This dataset consists of measurements made at the Vesivehmaa airfield during driving past artificial radionuclides (<sup>241</sup>Am, <sup>99m</sup>Tc, <sup>137</sup>Cs and <sup>60</sup>Co) at different distances ranging from 20 to 160 m and at different speeds (30km/h and 60 km/h). The measurements are of 2 and 5 sec duration.



Figure 7.5.1. The daily route in the Otaniemi area.



Figure 7.5.2. The daily route around the Helsinki Stadium (thick blue line) and The Marathon route (thinner green line).

#### 7.6 Finnish data processing

All measurements in Sonni are analysed in real time using the hypothesis test method described in Section 7.4.2. The algorithm searches for certain key nuclides, that are expected to be found in possible orphan sources or that can be obtained and used for malicious purposes.

In Figure 7.6.1 is an example of the hypothesis test outcome for the left NaI detector for three nuclides (<sup>99m</sup>Tc, <sup>137</sup>Cs and <sup>241</sup>Am), during a time period of slightly less than half an hour. The significance of <sup>99m</sup>Tc has a small positive bias, due to the shape of the spectrum in the area of the 141 keV peak. This offset is taken into account when setting the alarm levels in Sonni (not shown in picture), so for this nuclide a significance of 1.2, must be achieved for an alarm to go off. The same method is used when measuring in areas with real background (e.g. searching for a <sup>137</sup>Cs orphan source, in an area with significant <sup>137</sup>Cs fallout). As explained in Section 7.4.2, the risk level is set at 10<sup>-6</sup> so the <sup>99m</sup>Tc measurement with a high significance close to 10:51:40 is a real finding (probably an isotope patient, as the finding was made right outside a big hospital).



Figure 7.6.1. Significances output by the hypothesis test method used in Sonni. In this data period one finding of  $^{99m}$ Tc can be seen.

From the Vesivehmaa data, STUK calculated peak efficiencies and MDA's for the measured nuclides, at different distances from the car. One example of this can be seen in Figure 7.6.2.



Figure 7.6.2. Minimum detectable activity, MDA, for  $^{241}$ Am with data acquisition interval of 5 s and driving speed of 30 km/h as a function of distance between the source and the road. Measurements with low statistics are marked with square brackets ([]) (Ref. 13).

### 8 ACRONYMS

AGS	Airborne Gamma Spectrometry
ASSS	Area Specific Spectrum Stripping (previously ASS)
CGS	Carborne Gamma Spectrometry
DEMA	Danish Emergency Management Agency
DTU	Technical University of Denmark
FSC	Fitting with Spectral Components
LINSSI	LInux System for Spectral Information
MDA	Minimum Detectable Activity
NASVD	Noise Adjusted Singular Value Decomposition
NRPA	Norwegian Radiation Protection Agency
SONNI	Sophisticated On Site Nuclide Identification
SSI	Swedish Radiation Protection Authority
STUK	Radiation and Nuclear Safety Authority, Finland
UGS	Urban Gamma Spectrometry
USS	Unisampo-Shaman

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Title	Urban Gamma Spectrometry: Report 1
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Affiliation(s)	<ol> <li>Technical University of Denmark, Kgs. Lyngby, Denmark</li> <li>Radiation and Nuclear Safety Authority, Helsinki, Finland</li> </ol>
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No. of tables	17
No. of illustrations	65 (some of which are composites)
No. of references	13
Abstract	This report contains the present status and results for the NKS UGS-project per 1 June 2006 for NKS partners DTU, Denmark, and STUK, Finland. The Danish and Finnish CGS systems are not of similar types. The Danish CGS system(s) only make use of one Nal(Tl) detector whereas the Finnish CGS system consists of several detectors, Nal(Tl) and HPGe both and as an additional feature the Finnish detectors have position dependent different fields of view. Furthermore, the Finnish system is equipped with an air sampling system. In terms of operation, the Danish detector is located r on the rooftop whereas the Finnish detectors are located inside the vehicle. The Finnish and the Danish team use different methods for data processing. STUK uses a hypothesis test method to get robust real time alarms (within 10 seconds) when significant peaks from a previously defined set of nuclides are detected. An alarm for a significantly elevated total pulse rate is sent if none of the predefined nuclides is identified. All data are stored to the LINSSI database, which facilitates easy data retrieval for post processing. DEMA/DTU bases their calculations on full spectrum fitting using NASVD and the Danish software NucSpec. Source signals are found from spectrum fitting residuals or from stripping of energy windows – either by the standard 4-windows method or by a measurement based method where stripping factors for any window of interest can be derived from the measurements themselves. A thorough description of the two systems and data processing methods (including mathematics) are described in this report. For the Danish methods of data processing some comparisons have been made, but no final conclusion has been reached yet. Raw urban data has been investigated along with urban data sets to which source signals have been added and searched for. For the Finnish method calibration plots of the minimum detection limits for two different detector types have been made so far, and survey significance plots from drives around Helsinki during
Key words	Urban Carborne Gamma Spectrometry, Spectrum Stripping, Peak hypothesis, LINSSI, FSC, ASSS, NASVD