Geological Survey of Norway
N-7441 Trondheim, Norway
Tel.: 47 73 90 40 00
Telefax 47 73 92 16 20

# REPORT

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Title: Rapid environmental surveying using mobile gamma ray spectrometry: processing of results from the RESUME99 exercise, Gävle, Sweden.

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| Authors: Smethurst, Mark. A. | | Client: NGU/Nordic Nuclear Safety Research | |
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Summary:
Data from mobile measuring teams participating in the RESUME-99 Fixed Route exercise in Sweden have been processed to facilitate a detailed comparison between the data sets. The exercise was organised by the Swedish Radiation Protection Institute (SSI) and is part of the BOK-1.2 project *Mobile Measurements and Measurement Strategies* within the Nordic Nuclear Safety Research (NKS) programme for 1998-2000.

11 car-borne gamma ray spectrometer systems measured a fixed route in the vicinity of Gävle in Sweden so that the capabilities of the different measuring systems in determining the levels and patterns of $^{137}Cs$ contamination along the route could be studied. This report describes how the data sets from the different measuring systems were projected into the known trace of the fixed route so that the results can be compared. Estimates of equivalent surface activity of $^{137}Cs$ from the different measuring systems were normalised to data obtained by the Danish Emergency Management Agency (system DKA1) and then combined to produce an overall (cross-system) $^{137}Cs$ profile for the fixed route. Original and processed data are stored in ASCII text files on a CD that accompanies this report.

The Geological Survey of Norway (NGU) measured the fixed route 9 months after the RESUME-99 exercise. The NGU's results have been processed alongside the data from the exercise and a version of the overall cross-system $^{137}Cs$ profile has been produced that includes the NGU's measurements. The NGU's measurements are an important supplement to the data from RESUME-99 because the NGU's measuring system incorporates an NaI detector four times the volume of the largest detector used in the exercise. This permits a measuring interval half as long as the shortest interval used in the exercise, which leads to a higher spatial resolution for the NGU data.



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**Contents**

## 1. INTRODUCTION

This report describes the post-survey processing of radiation measurements from the RESUME-99 exercise that took place around Gävle in Sweden, September 6-9, 1999 (Karlsson et al. 2000). The exercise was organised by the Swedish Radiation Protection Institute (SSI) and is part of the BOK-1.2 project *Mobile Measurements and Measurement Strategies* within the Nordic Nuclear Safety Research (NKS) programme for 1998-2000. The main objective of the BOK-1.2 project is "*To investigate the feasibility of integrating different field measurements, mainly mobile equipment (car-borne and airborne), in the early phase of a nuclear emergency…*" (NKS, 1999). RESUME-99 was primarily aimed at testing mobile gamma spectrometry systems carried by cars, but also *in situ* measurements were carried out at fixed positions in the Gävle area.

Gävle was chosen for the exercise because there is a significant variation in activity of $^{137}$Cs in the region stemming from the Chernobyl accident in 1986. During the first day of measuring (September 7 1999) all mobile teams were instructed to measure along a fixed route 194 km in length (Fig. 1). The purpose of this exercise was to compare the response of the measuring systems to different radiation levels, road types and road surroundings. The fixed route was in the form of a closed loop passing through both rural and urban areas. Vehicles were instructed to travel as close to 50 km/h as possible and maintain a distance of 1 m from the roadside.

Six vehicles from 7 countries carried 17 separate measuring systems (Table 1, Fig. 2). Karlsson et al. (2000) offer a detailed description of the exercise and the different measuring systems and processing procedures used to obtain meaningful data values from them. The Geological Survey of Norway (NGU) was unable to participate in the RESUME-99 exercise in the autumn of 1999 and instead measured the fixed route on 22. May 2000. During the intervening time approximately 2% of the $^{137}$Cs in the environment will have decayed away. Also, some differences in the levels of radiation from $^{137}$Cs will arise from seasonal variations in soil moisture content and differences in the states of vascular plants that contain $^{137}$Cs. This permits only a general comparison between the levels of $^{137}$Cs recorded by the NGU system and the levels recorded during the exercise.

NGU's car-borne measuring system is based on a 16.7 litre NaI detector and 256-channel spectrometer (Table 1, Fig. 3, Smethurst 2000). The detector is more than four times the volume of the detectors used in the other measuring systems and permits an integration time of 1 second. Although the NGU system measured the fixed route in year 2000 and not during RESUME-99, the data are processed together with the RESUME-99 data because the measuring system is very different from the others and provides important additional information on the measuring efficiency of car-borne equipment.

| Country | Vehicle | Measuring system identifier | Detector (mounting) | Integration time | Spectrometer |
|---|---|---|---|---|---|
| Denmark | Golf | DKA1 | 4 l NaI(Tl) (external) | 2 s | 512 channels |
| | | DKB1 | 3" x 3" NaI(Tl) (internal) | 10 s | 256 channels |
| Estonia | Charlie | EEA1 | 4 l NaI(Tl) (external) | 2 s | 512 channels |
| Finland | Hotel | FIA3 | HPGe, 35% (internal) | 10 s | 2048 channels |
| | | FIA5 | PIC RSS112 (internal) | 30 s | Not applicable |
| | | FIA6 | G-M RADOS RD-102L (internal) | 30 s | Not applicable |
| Lithuania | Delta | LTA1 | 4 l NaI(Tl) (external) | 2 s | 512 channels |
| Latvia | Echo | LVA1 | 4 l NaI(Tl) (external) | 2 s | 512 channels |
| Poland | Foxtrot | PLA1 | 4 l NaI(Tl) (external) | 10 s | 512 channels |
| Sweden | Alpha | SEA1 | 3" x 3" NaI(Tl) (external) | 5 s | 256 channels |
| | | SEA3 | HPGe, 72.1% (external) | 10 s | 2048 channels |
| | Bravo | SEB1 | 3" x 3" NaI(Tl) (internal) | 10 s | 256 channels |
| | India | SEC1 | 3" x 3" NaI(Tl) (internal) | 10 s | 256 channels |
| **Post-survey measurements made by the Geological Survey of Norway:** | | | | | |
| Norway | NGU | NGU | 16.7 l NaI(Tl) (internal) | 1 s | 256 channels |

*Table 1. The mobile measuring systems used in the RESUME-99 exercise. Note that the Geological Survey of Norway (NGU) were unable to participate in the exercise in autumn 1999 and carried out their measurements in May 2000.*

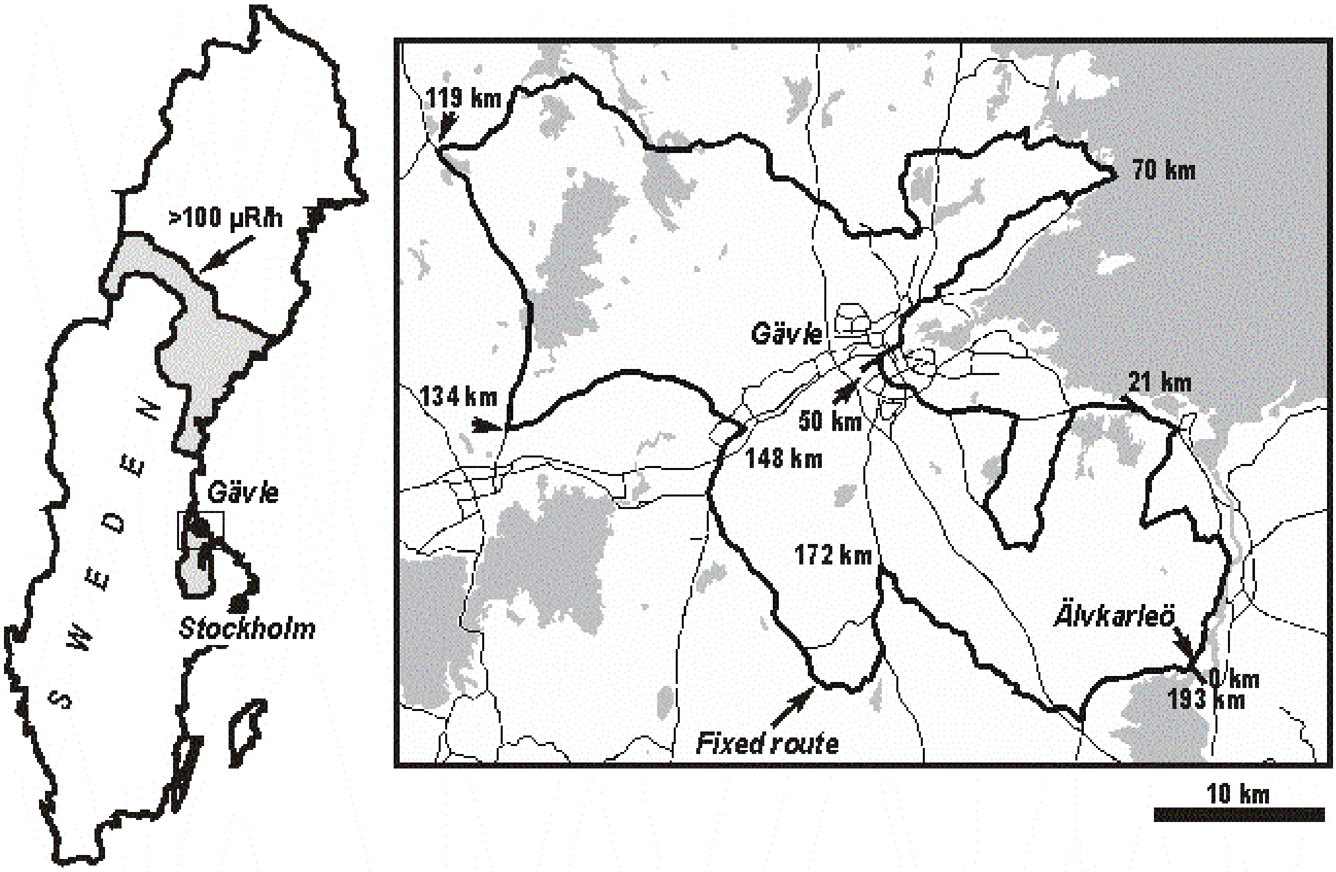


*Figure 1. Location of the RESUME-99 fixed route exercise. The shaded area on the map of Sweden is the region that received most fallout after the Chernobyl accident. The thick black line on the map of the Gävle region is the 193 km long fixed route.*


*Figure 2. The vehicles carrying mobile measuring systems in RESUME-99. From left to right: Sweden (Alpha), Denmark (Golf), Lithuania (Delta), Norwegian observer vehicle, Estonia (Charlie), Finland (Hotel), Latvia (Echo), Poland (Foxtrot). The calibration site at Älvkarelö Herregård.*

*Figure 3. The NGU's vehicle and measuring system at the calibration site at Älvkarelö Herregård.  This photo was taken in May 2000 when NGU measured the RESUME-99 fixed route. The side door is open so that the large NaI detector can be seen tilted towards the right side of the vehicle. The door is closed under normal operation of the measuring system.*

All vehicles recorded their passage through the fixed route using the satellite-based Global Positioning System (GPS). Some of the vehicles were equipped to carry out real-time differential correction of the GPS data (DGPS) to obtain more accurate estimates of their position. Navigational inaccuracies, gaps in navigational records due to temporary loss of GPS satellite coverage and other navigational errors led to significant differences between the recorded routes of the vehicles. These differences reach several hundred metres in places.

It is desirable to compare the spatial distribution of radiation sources along the fixed route as recorded by the different vehicles. It is also of interest to compare the car-borne results with airborne radiation measurements over the region. This can only be done if the differing navigational records of the vehicles can be linked to the precisely known position of the fixed route hereafter referred to as the *definitive route*.

The objectives of the reported processing work are to 1) establish the *definitive route*, 2) link the radiation measurements made by the different vehicles to positions in the *definitive route*, 3) produce a single data set for the *definitive route* based on results from all vehicles and 4) include airborne radiation measurements in the combined data set.

## 2. THE ORIGINAL DATA SETS

### 2.1 From the day of the exercise

The NKS files delivered by the measuring teams within the deadline of 22:00 set by the exercise organisers are listed in Table 2. Karlsson et al. (2000) describe the NKS file format.

| Measuring system | NKS File/s | Date and time for file |
|---|---|---|
| **DKA1** | DKA1L001.NKS | 07/09/1999 20:41 |
| **DKB1** | DKB1L001.NKS<br>DKB1L002.NKS<br>DKB1L003.NKS<br>DKB1L004.NKS | 07/09/1999 21:16<br>07/09/1999 21:29<br>07/09/1999 21:30<br>07/09/1999 21:31 |
| **EEA1** | EEA1L001.NKS<br>EEA1L002.NKS<br>EEA1L003.NKS<br>EEA1L004.NKS | 07/09/1999 19:46<br>07/09/1999 19:48<br>07/09/1999 19:52<br>07/09/1999 19:55 |
| **FIA3** | FIA3L001.NKS | 07/09/1999 20:51 |
| **FIA5** | FIA5L001.NKS | 07/09/1999 17:44 |
| **FIA6** | FIA6L001.NKS | 07/09/1999 17:52 |
| **LTA1** | LTA1L001.NKS<br>LTA1L002.NKS | 07/09/1999 23:10<br>07/09/1999 23:32 |
| **LVA1** | LVA1L001.NKS<br>LVA1L003.NKS | 07/09/1999 23:16<br>07/09/1999 18:22 |
| **PLA1** | PLA1L001.NKS | 07/09/1999 22:46 |
| **SEA1** | SEA1L001.NKS | 07/09/1999 17:04 |
| **SEA3** | SEA3L001.NKS | 07/09/1999 14:58 |
| **SEB3** | SEB1L001.NKS | 07/09/1999 21:03 |
| **SEC1** | SEC1L001.NKS | 07/09/1999 16:37 |

*Table 2. List of NKS files delivered by the mobile measuring teams to the RESUME-99 Computer and Communications Centre at Älvkarelö Herregård. These files can be found on the NGU's RESUME-99 processing CD in folder 'Initial data files'.*

### 2.2 The Geological Survey of Norway's data set

Table 3 shows the NKS file generated by the NGU in May 2000. The NGU's file, like those produced during the exercise, was generated before 22:00 on the day of measurement.

| Measuring system | NKS File/s | Date and time for file |
|---|---|---|
| **NGU** | NGU.NKS | 22/05/2000 19:41 |

*Table 3. The NKS file containing the NGU's data set for the fixed route acquired 22/05/2000. This file can be found in folder 'Initial data files' on the CD.*

Labels indicating data type accompany all data values in NKS files. For the purposes of the present processing exercise the labelling scheme has been extended to include the labels and data types shown in Table 4.

| New label/s | Meaning | Unit |
|---|---|---|
| Distance | Distance travelled | metres |
| X, Y | Edited and/or interpolated co-ordinates: the final co-ordinates for each data set. Swedish RT90 projection | metres |
| X_RT90_Dummy, Y_RT90_Dummy or X_WGS84_Dummy, Y_WGS84_Dummy | Original co-ordinates with navigational errors replaced by dummy values (zero or *). | metres |
| X_REF, Y_REF | Nearest position in the definitive route to the processed co-ordinates X, Y. | metres |
| REF_Distance | Distance from exercise start (along the definitive route) to X_REF, Y_REF. | metres |
| Deviation | Distance between X, Y and the nearest point (X_REF, Y_REF) in the definitive route. | metres |
| Declination | The bearing of X, Y from the nearest position in the definitive route (X_REF, Y_REF). | Degrees clockwise from projection 'north' |
| **Additions to the ends of labels** | **Meaning** | **Unit** |
| _n | The data are normalised to DKA1 according a function in Table 10. | As root label |
| _r | Gaps in the data have been interpolated over. See Table 9. | As root label |
| _m | MEDIAN data values derived from all but the NGU's measuring system (see below). Used only for the combined car $^{137}Cs$ result. | As root label |
| _m_NGU | Median data values (as above) where NGU data *are* included in the determination of the median. | As root label |

*Table 4. List of new labels used in processed NKS files. The upper part of the table summarises new labels while the lower part summarises appendages to labels that indicate which processing steps have been applied to the data.*

## 3. PROCESSING OF INDIVIDUAL DATA SETS

### 3.1 Definitive route and definitive distance travelled

The SSI provided the definitive route in the form of an ASCII file containing X_RT90 and Y_RT90. The file was created during a test-drive of the fixed route and is based on DGPS navigation.

The original file contained positions at irregular intervals along the road. *Minimum curvature interpolation* was used to generate two new versions of the route, one with X-Y co-ordinates every 10 m along the road, and the other with co-ordinates every metre (Table 5). The new files contain X_RT90, Y_RT90 and DISTANCE (in metres starting at the base of operations).

| File | Co-ordinate spacing |
|---|---|
| ROUTE.NKS | Irregular |
| ROUTE_10.NKS | Regular, 10 m |
| ROUTE_1.NKS | Regular, 1 m |

*Table 5. Files containing the definitive route. These files can be found in folder 'Fixed route' on the CD.*

### 3.2 Preliminary editing

Results for some vehicles were delivered in several NKS files (Table 2). These files were merged. Data records with obvious navigational errors were removed. Co-ordinates provided in *latitude/longitude* (geoid WGS84) were re-projected into the Swedish RT90 projection. Out of place data columns in the NKS file for measuring system FIA3 were corrected.

### 3.3 Interpolation of navigation

Breaks in navigation were common to all logging systems. This was mainly due to limited GPS satellite coverage in the lee of buildings and other large objects around the route. The percentages of missing/erroneous navigation points for all measuring systems are given in Table 6. Missing navigation points are indicated by dummy values 0 (zero) or * in data columns X_RT90_Dummy and Y_RT90_Dummy in processed NKS files (Tables 7 and 8).

| System | Valid navigation points after minor editing | Missing navigation points | Percentage missing navigation |
|---|---|---|---|
| DKA1 | 3694 | 7187 | 66 % |
| DKB1 | 1472 | 107 | 7% |
| EEA1[1] | 2744[1] | 6104[1] | 70%[1] |
| FIA3 | 1925 | 325 | 14% |
| FIA5 | 447 | 9 | 2% |
| FIA6 | 253 | 3 | 1% |
| LTA1[2] | 775[2] | 1992[2] | 72%[2] |
| LVA1 | 3144 | 6108 | 66% |
| PLA1 | 1765 | 0 | 0% |
| SEA1 | 3812 | 668 | 15% |
| SEA3 | 1980 | 25 | 1% |
| SEB3 | 837 | 98 | 11% |
| SEC1 | 1129 | 648 | 37% |
| NGU | 18988 | 4735 | 20% |

*Table 6. The occurrence of successful and unsuccessful navigational fixes for the different measuring systems. [1]Erroneous navigation between 21 km and 50 km. [2] No measurements after 50 km.*

Linear interpolation was used to fill all gaps in the navigational records. Larger gaps in the records were re-created at a later stage in the processing.

### 3.4 Splitting the route into three sections

Vehicles were required to drive in both directions down roads in the vicinity of calibration sites Ytterharnäs (at 21 km) and Regementsparken (at 50 km). This results in difficulties in comparing actual vehicle positions with the *definitive route* near the sites. When individual vehicle positions are compared with the *definitive route* without regard for direction of travel, uncertainty arises as to whether a vehicle is on its way *to* the calibration site or on its way *from* the calibration site. To simplify the comparison procedure all data sets were split at the two calibration sites to produce three route segments (0 – 21 km, 21 – 50 km, 50-193 km). This ensured that data acquired travelling to and from the calibration sites were not inadvertently interchanged.

## 3.5 Projecting vehicle routes into the definitive route

### 3.5.1 X_REF, Y_REF, REF_Distance

The projection procedure was carried out separately on the three route segments outlined above. Each estimate of vehicle position (measured or interpolated) was compared with positions at 1 m and 10 m intervals along the *definitive route*. The closest position in the *definitive route* to the vehicle (X_REF, Y_REF) is taken to be a better estimate of the *actual* position of the vehicle. The distance of position X_REF, Y_REF along the *definitive route* is taken to be the *definitive distance* travelled by the vehicle (REF_Distance). *Definitive distance* (REF_Distance) relates all vehicle measurements to precise distances along a single route and in so doing permits direct comparison between radiation measurements made by the different vehicles.

### 3.5.2 'Deviation'

The distance between each estimate of vehicle position (X, Y) and the nearest point in the *definitive route* (X_REF, Y_REF) was calculated and given the label 'Deviation'. 'Deviation' is used in a later processing stage to eliminate measurements with poor navigation that lie far from the *definitive route*.

### 3.5.3 'Declination'

The bearing of a line drawn from the definitive route at X_REF, Y_REF to the observed (or interpolated) vehicle position (X, Y) was calculated and labelled 'Declination'. Declination is in degrees clockwise from projection 'north' and can be used to identify systematic offsets between the routes recorded by the measuring systems and the *definitive route*.

### 3.5.4 1 m resolution and 10 m resolution

Data sets were projected into high resolution and low-resolution versions of the *definitive route* (1 m and 10 m co-ordinate intervals respectively). The files containing the projected data are listed in Table 7. Both sets of files can be used for cross-vehicle comparison of radiation measurements.

| System | 1 m resolution | 10 m resolution |
|---|---|---|
| DKA1 | DKA1_P1.NKS | DKA1_P10.NKS |
| DKB1 | DKB1_P1.NKS | DKB1_P10.NKS |
| EEA1 | EEA1_P1.NKS | EEA1_P10.NKS |
| FIA3 | FIA3_P1.NKS | FIA3_P10.NKS |
| FIA5 | FIA5_P1.NKS | FIA5_P10.NKS |
| FIA6 | FIA6_P1.NKS | FIA6_P10.NKS |
| LTA1 | LTA1_P1.NKS | LTA1_P10.NKS |
| LVA1 | LVA1_P1.NKS | LVA1_P10.NKS |
| PLA1 | PLA1_P1.NKS | PLA1_P10.NKS |
| SEA1 | SEA1_P1.NKS | SEA1_P10.NKS |
| SEA3 | SEA3_P1.NKS | SEA3_P10.NKS |
| SEB3 | SEB1_P1.NKS | SEB1_P10.NKS |
| SEC1 | SEC1_P1.NKS | SEC1_P10.NKS |
| NGU | no file generated | NGU_P10.NKS |

*Table 7. Files containing data sets where the navigational data are projected (snapped) directly into the definitive route. Two versions of the definitive route were used, one with a coordinate spacing of 1 m and the other with a spacing of 10 m (Table 5). These files can be found on the NGU's RESUME-99 processing CD in folder 'Data projected into fixed route'.*

The two sets of files have the same number of data records but differ in X_REF, Y_REF, REF_Distance, Deviation and Declination. Successive navigation points in the '1 m' projected data sets seldom project into the same reference position in the high-resolution *definitive route*. Therefore, for the most part, REF_Distance (*definitive distance*) increases from one projected data record to the next. This is not the case for the '10 m' projected data sets. Where the vehicles travelled slowly or turned sharp corners, original navigation points are close together and project into the same 10 m-resolution point in the *definitive route*. This leads to small sections of projected data with repeated REF_Distance (*definitive distance*) values.

*Important note:* At this processing stage no account is taken of the apparent distance between the vehicle and the reference path (the parameter labelled 'Deviation'). When 'Deviation' is large, the navigational fix on the vehicle is poor (i.e. the vehicle's route does not conform with the *definitive route* - even approximately). Data records with 'Deviation' in excess of 100 m or so cannot reliably be compared on a spatial basis with results from other vehicles. These data are removed at the next processing stage where vehicle position must be well known.

# 4. PRODUCTION OF A COMBINED DATA SET AT 10 M RESOLUTION

## 4.1 Preparation of individual data sets

Representatives of the teams taking part in the exercise decided that a combined data set for all vehicles should have data values at 10 m spacing along the route. The '10 m'-projected data sets in Table 7 were used as the starting point for the preparation of this combined data set.

### 4.1.1 Sorting data records according to (definitive) distance travelled

Small sections of some of the vehicle routes backtrack when projected into the *definitive route*. This has several causes. The most obvious is that one or two vehicles reversed/turned back short distances along the road. Also the logged positions of stationary or slow-moving vehicles scatter back and forth and to the sides of the *definitive route*. Finally, backtracking along the definitive route was also noticed around several sharp corners in the route. This results from uncertainty in the direction to project the data when the *definitive route* has a complicated shape on a scale similar to the 'Deviation' of the measured routes.

Backtracking is easily detected in the projected NKS files listed in Table 7. The data item REF_Distance decreases over one or more records and then increases again. The projected NKS files listed in Table 7 are not sorted according to distance along the reference route so the data item REC (original measurement record number) still increases 'downwards' in the files.

Sorting of the projected data records according to distance along the definitive route is necessary if the results for the various vehicles are to be combined into a single table (file). Sorting was carried out at two levels: the data records were primarily sorted by REF_Distance (distance along the route) and then by REC (original record number).

### 4.1.2 Removing duplicate measurements

It is not unusual in the projected NKS files that successive data records project into a single position in the *definitive route.* This is, of course, more pronounced in the files projected into the '10 m' *definitive route* than in files projected into the '1 m' *definitive route*. Given that the combined data file is to contain no more than one data record from each vehicle at each (10 m) position along the route, *all but the first of the multiple records were deleted*.

### 4.1.3 Removing data with outlying position

Sections of data sets that lay a significant distance from the *definitive route* were removed. All data records with 'Deviation' in excess of 100 m were deleted. At this distance, projection into the *definitive route* is unreliable.

NKS files containing sorted records with multiple and outlying records removed are listed in Table 8.

| System | NKS file | Integration time | Records remaining |
|---|---|---|---|
| DKA1 | DKA1_F10.NKS | 2 s | 8096 (of 19344) |
| DKB1 | DKB1_F10.NKS | 10 s | 1454 (of 19344) |
| EEA1 | EEA1_F10.NKS | 2 s | 6891 (of 19344) |
| FIA3 | FIA3_F10.NKS | 10 s | 1826 (of 19344) |
| FIA5 | FIA5_F10.NKS | 30 s | 321 (of 19344) |
| FIA6 | FIA6_F10.NKS | 30 s | 186 (of 19344) |
| LTA1 | LTA1_F10.NKS | 2 s | 728 (of 19344) |
| LVA1 | LVA1_F10.NKS | 2 s | 8465 (of 19344) |
| PLA1 | PLA1_F10.NKS | 10 s | 1762 (of 19344) |
| SEA1 | SEA1_F10.NKS | 5 s | 3310 (of 19344) |
| SEA3 | SEA3_F10.NKS | 10 s | 1679 (of 19344) |
| SEB3 | SEB1_F10.NKS | 10 s | 854 (of 19344) |
| SEC1 | SEC1_F10.NKS | 10 s | 1236 (of 19344) |
| NGU | NGU_F10.NKS | 1 s | 14635 (of 19344) |

*Table 8. Files containing projected data sets that have been filtered to remove records that lie far from the definitive route and to remove multiple records for individual positions in the 10 m resolution route. These files can be found on the NGU's RESUME-99 processing CD in folder 'Data projected and filtered'. Note that measuring systems with long integration times like FIA5 and FIA6 (30 s) have fewest data before and after filtering.*

### 4.2 Combining all data sets into a single table

The data sets in Table 8 were combined into a single file using REF_Distance (*definitive distance*) as a key:

**File: ALL_F10.NKS**

This file can be found in folder 'Combined data files'on the NGU's RESUME-99 processing CD.

The route stored in the combined file is the '10 m' *definitive route*. Original record number (REC) and *all* radiation measurements were taken from the individual data sets. All measuring systems used standard NKS-type labels for different kinds of radiation measurements. Measuring system identifiers (e.g. DKA1) were added to the data labels in the merged file to differentiate between results from different measuring systems. For example, the label DKA1_AE_CS137 in the combined file refers to the AE_CS137 measurement for system DKA1.

### 4.3 Interpolation of data across small breaks in the combined data set

Small gaps between data records were interpolated over. This was done differently for data from the different measuring systems. Linear interpolation was used to fill gaps when those gaps were less than or equal to the lengths outlined in Table 9.

Combined file with interpolation: **ALL_R10.NKS**

This file can be found in folder 'Combined data files' on the NGU's RESUME-99 processing CD.

The processed estimates of equivalent surface activity of $^{137}$Cs in the combined file (Labels ending AE_CS137) are plotted against distance travelled in Figure 4a. Note that the curves for the different measuring systems differ in amplitude because of inconsistencies in the calibration of the instruments used.

| **System** | **Maximum gap to interpolate (m)** | **Pre-interpolation records** | **Post-interpolation records** |
|---|---|---|---|
| DKA1 | 100 | 8093 | 19157 (of 19344) |
| DKB1 | 200 | 1454 | 16291 (of 19344) |
| EEA1 | 100 | 6891 | 16342 (of 19344) |
| FIA3 | 200 | 1826 | 16837 (of 19344) |
| FIA5 | 1000 | 321 | 16293 (of 19344) |
| FIA6 | 1000 | 186 | 9220 (of 19344) |
| LTA1 | 200 | 728 | 3866 (of 19344) |
| LVA1 | 100 | 8465 | 19332 (of 19344) |
| PLA1 | 150 | 1762 | 18520 (of 19344) |
| SEA1 | 100 | 3310 | 18805 (of 19344) |
| SEA3 | 200 | 1679 | 19221 (of 19344) |
| SEB3 | 200 | 854 | 8815 (of 19344) |
| SEC1 | 200 | 1236 | 13675 (of 19344) |
| NGU | 100 | 14618 | 18954 (of 19344) |

*Table 9. A list of the maximum lengths of gaps to be interpolated over.*

## 5. INCORPORATING AIRBORNE MEASUREMENTS INTO THE TWO COMBINED FILES

To compare the car-borne data with airborne data the SSI sampled a the Swedish Geological Survey's (SGU's) fixed-wing data set for the Gävle region along the *definitive route*. This was done by first interpolating the flight-line data onto a regular grid and then extracting values from the grid along the 10 m resolution *definitive route*. The sampled airborne data are stored in file **AIRBORNE.NKS** (folder 'Initial data' on the CD) and in the combined files **ALL_F10.NKS** and **ALL_R10.NKS** (Label AIR_CS137) and plotted in Figure 4a.

## 6. COMBINING RESULTS FROM ALL VEHICLES INTO A SINGLE RESULT FOR THE FIXED ROUTE

It is interesting to establish whether the data sets for the various vehicles can be usefully combined to produce an overall picture of the variation in $^{137}$Cs activity along the fixed route. This requires cross-calibration between the different measuring systems and then the implementation of some procedure to obtain a single $^{137}$Cs activity for any particular place along the fixed route from several measuring systems.

It was decided at a post-exercise meeting to normalise measurements from all systems to those obtained from DKA1. Linear regression was performed on the individual data sets *versus* DKA1 between 0 m and 18450 m along the fixed route (Fig. 5 and Table 10). One group of measuring systems produced values 1.7 to 1.9 times those obtained from DKA1, and the other group gave values between 0.5 and 0.7 times DKA1 results. The question of which calibration is the best is beyond the scope of this report. Note that data from PLA1 have a large positive offset from DKA1 (when DKA1 reads 0 Bq/m$^2$, PLA1 reads 9897 Bq/m$^2$). Note also that DKB1 correlates poorly with DKA1 at high $^{137}$Cs activities (regression coefficient $R^2$ = 0.6857)

To generate a uniformly calibrated suite of data sets the $^{137}$Cs measurements in the combined files were normalised to DKA1 according to the functions in Figure 5 and Table 10. The normalised data have NKS labels ending '_n' in files ALL_F10.NKS and ALL_R10.NKS (CD folder 'Combined data files'). Normalised equivalent surface activities for $^{137}$Cs are plotted against distance travelled in Figure 4b. The normalised curves in Figure 4b are in close agreement over much of the fixed route.

| System | Linear function relating Systems to DKA1 | Regression coefficient $R^2$ |
|---|---|---|
| FIA5 | No Cs-137 measurement | - |
| FIA6 | No Cs-137 measurement | - |
| Reference measuring system for cross calibration: | | |
| DKA1 | = 1.000 x DKA1 + 0.00 | - |
| Systems that yield activities higher than DKA1: | | |
| EEA1 | = 1.8361 DKA1 + 1890.40 | 0.9528 |
| LTA1 | = 1.7576 DKA1 + 2299.20 | 0.9119 |
| LVA1 | = 1.8754 DKA1 + 423.45 | 0.9391 |
| PLA1 | = 1.7656 DKA1 + 9896.50 | 0.8943 |
| Systems that yield activities lower than DKA1: | | |
| DKB1 | = 0.6434 DKA1 - 487.91 | 0.6857 |
| FIA3 | = 0.5356 DKA1 + 1141.90 | 0.8613 |
| SEA1 | = 0.6338 DKA1 + 182.03 | 0.8948 |
| SEA3 | = 0.6792 DKA1 - 664.58 | 0.9037 |
| SEB3 | = 0.4921 DKA1 - 19.75 | 0.8449 |
| SEC1 | = 0.4838 DKA1 + 79.87 | 0.8720 |
| NGU | = 0.4655 DKA1 + 137.19 | 0.8609 |
| Airborne | = 2.7778 DKA1 | - |

*Table 10. The linear functions used to normalise measurements of $^{137}$Cs activity from the different measuring systems to those from DKA1. Note that these functions are based on measurements made on the fixed route between 0 m and 18450 m. The normalised data (with NKS labels ending _n) are in files ALL_F10.NKS and ALL_R10.NKS (CD folder 'Combined data files').*


*Figure 4a. Equivalent surface activity Cs-137 for the fixed route:, all measuring systems.*


*Figure 4b. Equivalent surface activity Cs-137 for the fixed route: data from all measuring systems normalised to DKA1.*


*Figure 4c. Equivalent surface activity Cs-137 for the fixed route. Two versions of a combined car result have been produced. These were generated by extracting median data values from the normalised car-borne data sets in Figure 4b. The blue profile includes data from the NGU car while the red profile does not.*

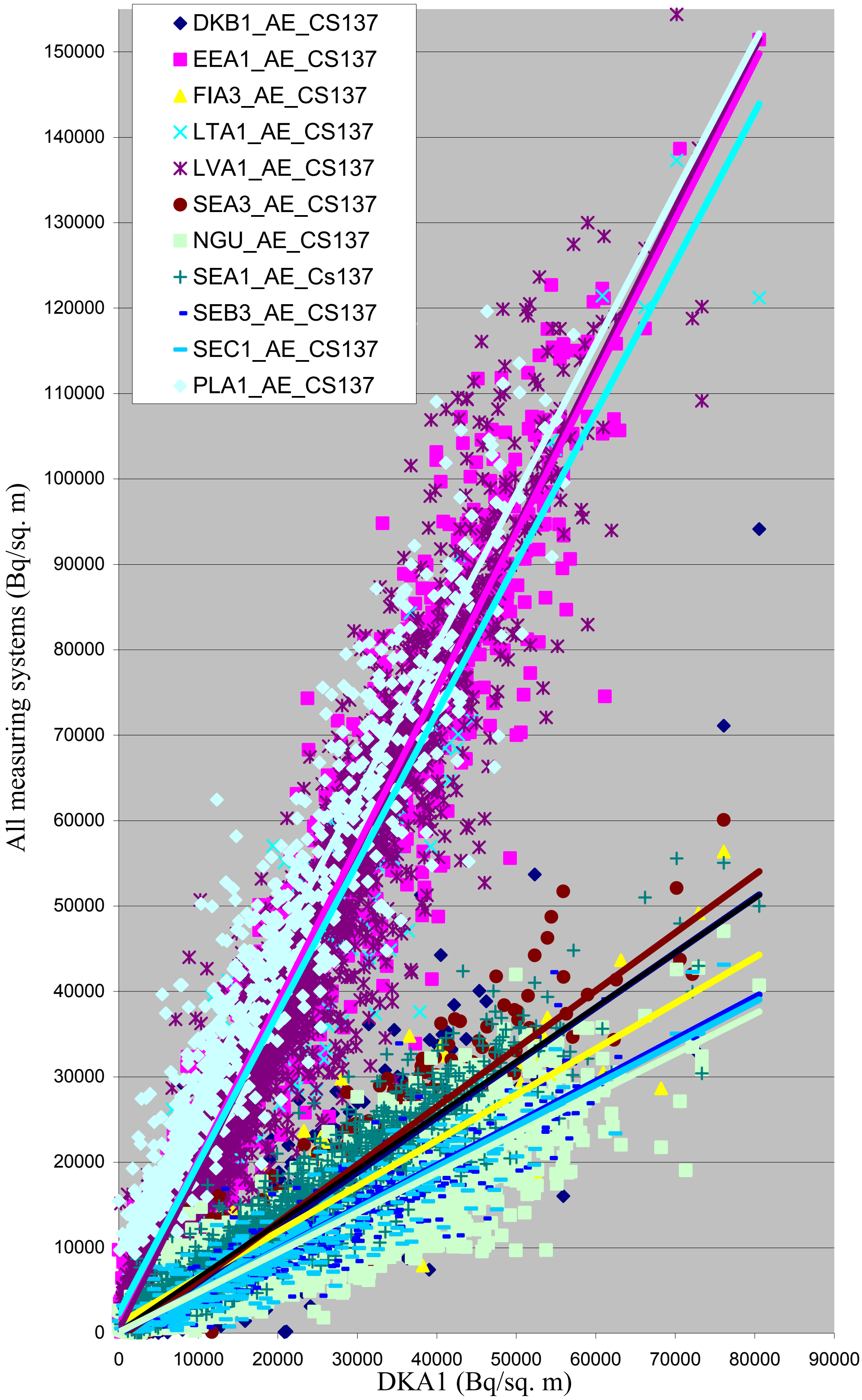


*Figure 5. Equivalent surface activity Cs-137 for all measuring systems versus DKA1 (fixed route, between 0 and 18450 m).*

The normalised $^{137}Cs$ data sets for the different measuring systems were reduced to a single overall result for the fixed route by selecting the *median* measurement for each 10 m position along the route. If there were an even number of measurements for a particular position, the average of the two middle values was taken to be the median. If there were no measurements for a position in the route, a dummy value was assigned to that position. The median data set has the label 'AE_CS137_n_m_NGU' in files ALL_F10.NKS and ALL_R10.NKS (CD folder 'Combined data files'). Note that the NGU did not measure the fixed route at the same time as the other mobile systems so a version of the combined (median) data set was produced without data from the NGU and given the label 'AE_CS137_n_m'. Both median results are plotted against distance travelled in Figure 4c. The median car result based on all data (including the NGU's) is plotted on a map of the Gävle region in Figure 6. This is then the best estimate of distribution of $^{137}Cs$ along the fixed route founded on 12 independent surveys of that route.

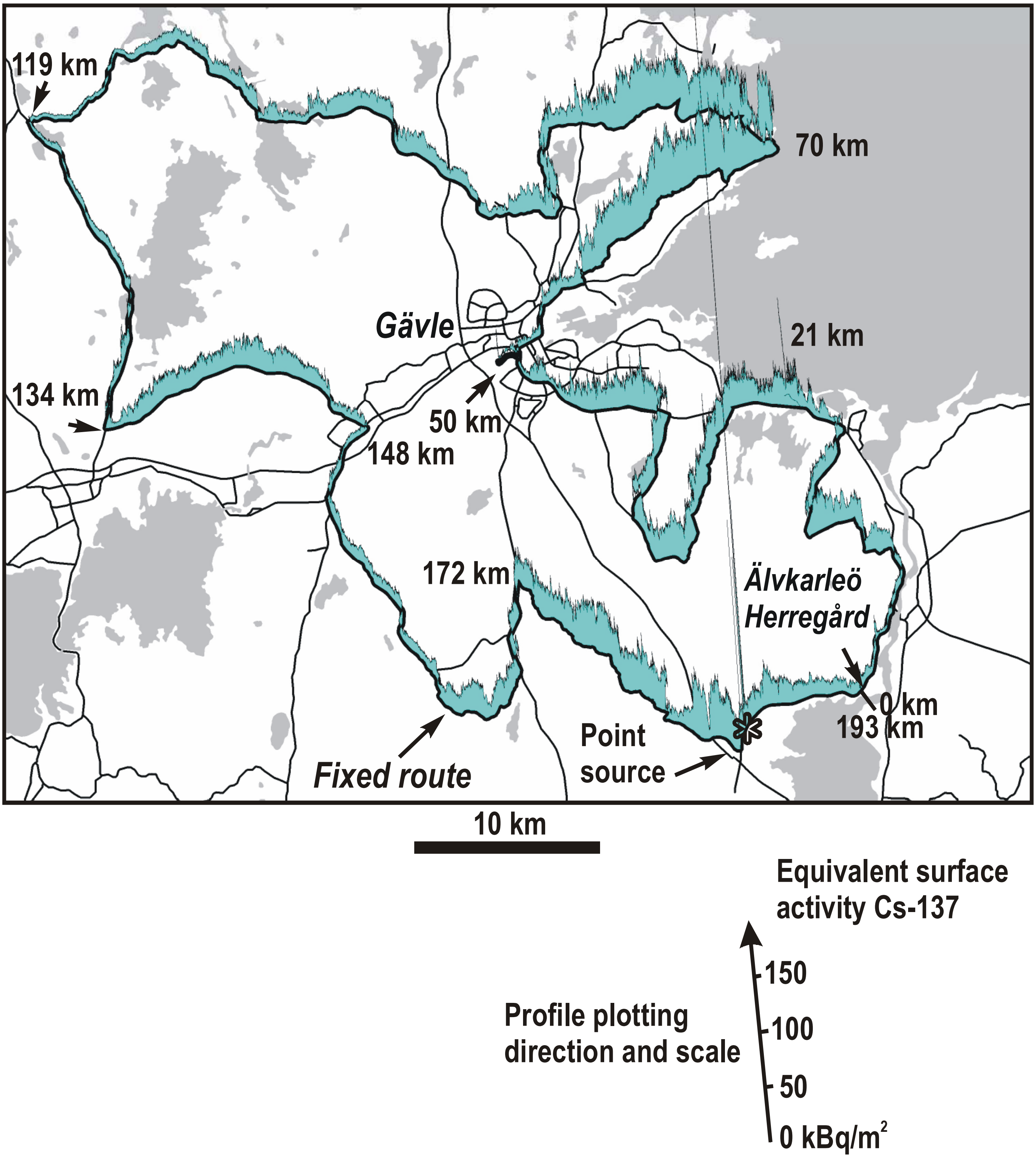


*Figure 6. Profile plot of the combined ('median car') result. The plotting direction for equivalent surface activity is indicated by the arrow below the map. Note that the combined result shown on the map includes data from the NGU car. Data sets from the different cars were first normalised to DKA1 before they were combined by selecting the median of all available results for each position along the road..*

## 7. THE CONSISTENCY BETWEEN MEASUREMENTS MADE BY DIFFERENT TYPES OF MEASURING SYSTEM

Table 11 is a summary of the contributions made by the different measuring systems to the final median data set for the fixed route (Figure 6). Systems FIA5 and FIA6 did not measure equivalent surface activity of $^{137}Cs$ and therefore they do not contribute data to the median data set. The measuring systems with shortest integration time generally contribute more data to the final curve, simply because they produce a measurement more often. The NGU's system, with its high measuring rate, contributes most data. The NGU's system made a valid measurement every 13.2 m on average along the fixed route and provided measurements close to 76% of the 10 m positions along the route (calculated from Table 9). Normalising the contributions of data to sampling interval provides an indication of how alike the data from the measuring systems are after normalisation to DKA1 (Table 11). The normalised contributions from systems DKA1, EEA1, LVA1, PLA1, FIA3, SEA3 and NGU are between 11% and 13%. This indicates that those systems produced data values that often lie in the middle of the scatter of data values from the different measuring systems. The aforementioned systems have either medium to large NaI detectors or HpGe detectors. Systems SEC1, SEB3, SEA1, DKB1 and LTA1 contributed fewer data to the median data set. With the exception of LTA1 these systems have small NaI detectors, usually mounted inside the vehicle. LTA1 contributes little to the median result because the system mapped only the first 50 km of the 193 km route.

| System | Percentage of median data set (%) | Integration time | Percentage of median data set normalised to integration time (%) | Detector |
|---|---|---|---|---|
| FIA5 | No data | | | |
| FIA6 | No data | | | |
| DKA1 | 16 | 2 s | 12 | Medium NaI external |
| EEA1 | 16 | 2 s | 12 | Medium NaI external |
| LTA1 | 1 | 2 s | 1 | Medium NaI external |
| LVA1 | 18 | 2 s | 13 | Medium NaI external |
| PLA1 | 3 | 10 s | 11 | Medium NaI external |
| DKB1 | 1 | 10 s | 4 | Small NaI internal |
| FIA3 | 3 | 10 s | 11 | HPGe internal |
| SEA1 | 5 | 5 s | 5 | Small NaI external |
| SEA3 | 3 | 10 s | 11 | HPGe external |
| SEB3 | 1 | 10 s | 4 | Small NaI internal |
| SEC1 | 2 | 10 s | 7 | Small NaI internal |
| NGU | 31 | 1 s | 11 | Large NaI internal |

*Table 11. The occurrence of data from the different measuring systems in the combined (median) data set represented as a percentage of the whole data set. The median data set has the label 'AE_CS137_n_m_NGU' in files ALL_F10.NKS and ALL_R10.NKS (CD folder 'Combined data files'). Note that the NGU did not measure the fixed route at the same time as the other mobile systems so a version of the combined (median) data set was produced without data from the NGU and given the label 'AE_CS137_n_m'.*

## 8. CONCLUSIONS

Data from mobile measuring teams participating in the RESUME-99 Fixed Route exercise in Sweden have been processed to facilitate a detailed comparison between the data sets. Eleven car-borne gamma ray spectrometer systems measured a fixed route in the vicinity of Gävle in Sweden so that the capabilities of the different measuring systems in determining the levels and patterns of $^{137}$Cs contamination along the route could be studied. This report describes how the data sets from the different measuring systems were projected into the known trace of the fixed route so that the results can be compared. Estimates of equivalent surface activity of $^{137}$Cs from the different measuring systems were normalised to data obtained by the Danish Emergency Management Agency (system DKA1) and then combined to produce an overall (cross-system) $^{137}$Cs profile for the fixed route. Original and processed data are stored in ASCII text files on a CD that accompanies this report. The text files are in 'NKS' format, a file format developed by participants in the Nordic Nuclear Fission Safety Research BOK-1.2 project for the easy and reliable exchange of data between Nordic countries.

The NGU was unable to participate in the RESUME-99 exercise and instead measured the fixed route some months later in May 2000. The NGU's results have been processed alongside the data from the exercise and a version of the overall cross-system profile has been produced that includes the NGU's measurements. The NGU's measurements are an important supplement to the data from RESUME-99 because the NGU's car-borne gamma ray spectrometer system incorporates an NaI detector that is four times the volume of the largest detector used in the exercise. This permits a measuring interval half as long as the shortest interval used in the exercise, which leads to a higher spatial resolution for the NGU data. This is borne out by the fact that peaks and troughs in the NGU's data for the fixed route have higher amplitudes than corresponding peaks and troughs in data from the other measuring systems.

## 9. REFERENCES


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