The distribution of radioactive fall-out in Nord-Trøndelag from detailed airborne and ground-gamma ray spectrometer surveying

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One important outcome of NGU's detailed airborne geophysical surveying in the Nord-Trøndelag district has been the accumulation of information on the spatial distribution of radioisotopes -- including man-made ones like caesium (^{137}Cs and ^{134}Cs), the principal constituents of Chernobyl fall-out in Scandinavia. The potential of the new data for environmental investigation and monitoring inspired a new scientific co-operation between NGU and the Norwegian Institute for Nature Research (NINA). The first results of that co-operation are summarised here.

Following the nuclear accident at Chernobyl in April 1986, parts of Norway received significant amounts of radioactive fall-out. Nord-Trøndelag and central parts of southern Norway were amongst the worst affected areas. In 1986 it was known that the distribution of fall-out in these two regions was patchy, yet there were too few ground or airborne measurements available to accurately map the extent of local radiation highs (on the scale of individual municipalities). Nevertheless, in 1986 an overview of the fall-out pattern could be deduced *indirectly* from, for example, radiation levels in agricultural produce, fresh water fish, game, berries and edible fungi.

Airborne mapping

Airborne gamma ray spectrometry is perhaps the cheapest and fastest method of directly measuring radiation levels over large regions. This method of delineating radiation sources on the ground has been widely used in mineral exploration and environmental programmes around the world. Within 6 weeks of the Chernobyl incident, an overview of the fall-out pattern in Sweden was presented in map form by the Swedish Geological Company (SGAB). The map showed a broad belt of radioactive fall-out passing from the Baltic coast between Gävle and Umeå in a northwesterly direction over the Norwegian-Swedish border into Nord-Trøndelag and Nordland. Ground radiation levels of more than 80 kBq/m^2 (^{137}Cs, 1986) were recorded (from the air) in Sweden adjacent to the Lierne and Røyrvik municipalities. This is consistent with the more generalised fall-out map for Nord-Trøndelag and Nordland --based on only 4 soil samples per municipality-- where radiation levels were reported to exceed 80 kBq/m^2 (^{137}Cs, 1986; cf. the National Institute of Radiation Hygiene and Norwegian Mapping Authority).

NGU's record in radiation mapping

NGU has more than 30 years experience in airborne radiation surveying. Helicopter-borne surveying in Nord-Trøndelag began as long ago as 1975 and in the last few years has benefited from the guidance of R.L. Grasty, consultant to the International Atomic Energy Agency. Until recently, attention was paid only to natural radiation sources (rocks) given that the measurements were made as part of a programme of geological mapping and mineral resource assessment. Nevertheless, most of the data from surveys post-dating the Chernobyl accident could be re-processed to extract information on *man-made* radioisotopes such as ^{137}Cs, the main constituent of the Chernobyl fall-out in Scandinavia. We have now done this for the Nord-Trøndelag surveys and produced a single overview ^{137}Cs map (Fig. 1). Unfortunately the surveys were located according to geological considerations rather than environmental ones. They therefore do not cover the whole of the Nord-Trøndelag region, or even all of those regions known to have received larger quantities of fall-out. Nevertheless, the newly processed data sets and compilation map provide an unprecedented (in Norway) regional picture of the distribution of Chernobyl fall-out (based on 30,000 profile km covering 6,000 km^2). Indeed, the maps produced by NGU are based on profiles flown at intervals of 100 to 250 m; much more

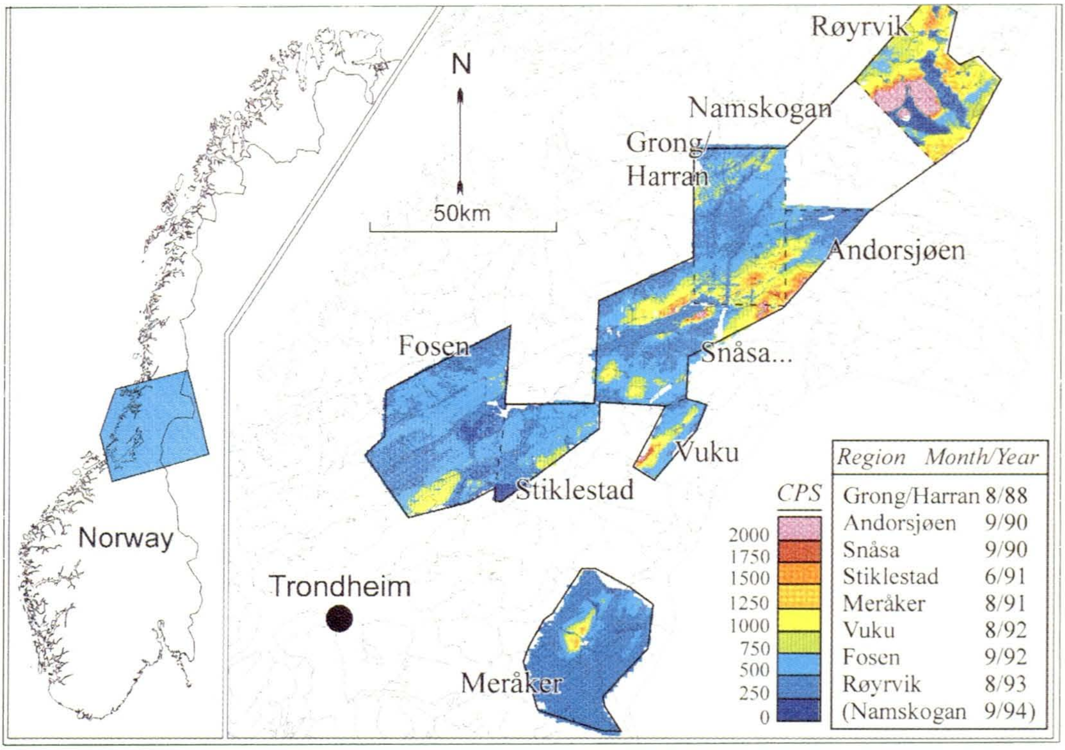

Fig. 1. NGU's airborne gamma ray spectrometer surveys in Nord-Trøndelag. CPS: counts per second. Based on a map at scale 1:500,000.

detailed than most surveys designed with regional fall-out mapping in mind.

Data processing

We have combined 8 separate surveys carried out between 1988 and 1994. Gamma radiation associated with ^{137}Cs was first separated from radiation associated with other radionuclides. Then the resulting ^{137}Cs *counts per second* (CPS) at measuring height (60m) were adjusted to yield apparent *ground count-rates.* The various data sets, obtained over 5 years, were adjusted to a *common time* (1 May 1986) according to the exponential decay constant 0.023 per year. A compilation contour map of ^{137}Cs count-rates (at *ground-level back calculated to 1986)* was then produced.

Radiation levels

Count-rate maps accurately delineate areas that received different amounts of fall-out but offer no *standard* measure of actual radiation levels. At NGU we have calibrated our airborne spectrometer (Exploranium GR800 with DET-1024 16.8l NaI detector; Walker & Smethurst 1993). That calibration suggests that that our *counts per second* (airborne equipment) can be converted to the standard unit *kBq/m²* using a multiplication factor of 0.04. This being so, the maximum contour on our compilation map (Fig. 1) corresponds to approximately 80 kBq/m^2 (apparent ground-concentration ^{137}Cs back calculated to 1986). This agrees very well with the results of the airborne measurements made in Sweden back in 1986 that revealed local radiation highs exceeding 80 kBq/m^2 (^{137}Cs) across the border from the Lierne municipality.

The regions on our map which appear to have had 1986 levels of radiation due to ^{137}Cs in excess of 80 kBq/m^2 are (1) The Tunnsjøen district, (2) smaller areas bordering Snåsavatnet, (3) an area east of Snåsa and (4) a small area in the Vuku valley.

Ground-resolution of the airborne surveys

The airborne instrument detects radiation emit-

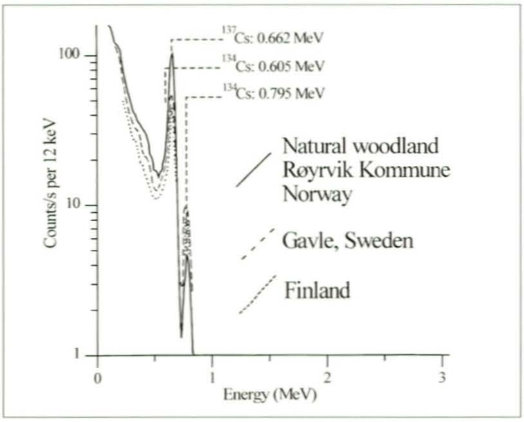

Fig. 2. Comparison of gamma ray spectra from Nord-Trøndelag, Sweden and Finland (spectra from Sweden and Finland c.f. R.L. Grasty, Geological Survey of Canada).

ted by an oval area on the ground measuring approximately 150 by 200 metres and therefore is an average reading of the ground, plant communities and trees in an area of 25,000 m^2. In regions of higher radioactive contamination in Nord-Trøndelag it is usually the case that the radiation level over improved ground, such as a farmer's field, is significantly lower than over the surrounding natural terrain (for example woodland). In this case the farmland would have to be maybe 500 metres across before a faithful recording of the radiation emitted by the field could be distinguished (on our 1:50,000 scale maps) from that emanating from the surrounding countryside. Any abrupt change in radiation level on the ground, like at the edge of a field, will appear somewhat blurred on the map.

Ground-truth

Any airborne radiometric survey should be accompanied by a programme of follow-up ground-measurements to test the authenticity of the anomalies and to find out exactly where in the environment the radiation is concentrated. We have done this in the Nord-Trøndelag region using a hand-held spectrometer calibrated in the manner described by Grasty et al. 1992 (Equipment: Exploranium GR-256 with GPS-21 3"x3" NaI detector).

Figures 2 and 3 are the products of ground follow-up work. Ground-spectrometry is rather like airborne work in that it provides an indication of the overall radiation emitted by an area of ground, only that the area is much smaller (approximately 4 m across with the detector at 40 cm elevation). Gamma-ray spectra from the *centre* of the 'high' in the Røyrvik municipality closely resemble spectra from the worst affected parts of Sweden (Gävle) and Finland (Fig. 2).

Figure 3 is a ^{137}Cs map of an area measuring 18 by 24 m produced by ground-surveying. The area is in the middle of the anomaly north of Meråker, yet there is a huge local variation in radiation level over just a few metres. The *amplitude* of such local features were found to approach that of the whole anomaly (6 km across), reaffirming the importance of a combined regional (airborne) and local (ground) approach to radiation mapping. So far we have noted a good spatial correlation between radiation 'highs' on our maps and instances of relatively high ^{137}Cs contamination in plants and meat. Helicopter measurements suggest that *average* radiation levels at the centre of the anomaly northwest of Tunnsjøen might reach 150 to 250 kBq/m^2 (1986). Our *maximum* ground measurement in this area was 200 kBq/m^2 (1994, Fig. 2), confirming the airborne result. The radiation level in meat from sheep grazing in the area was recently measured to be comparatively high at around 5000 Bq/kg (^{137}Cs+^{134}Cs), and in fish from Tunnsjøen at 8400 Bq/kg (^{137}Cs+^{134}Cs; analyses carried out by the *Næringsmiddelkontrol* in Namdal). This spatial correlation between radiation highs from airborne mapping and high levels of contamination in plants and meat demonstrates the immense value of airborne mapping in

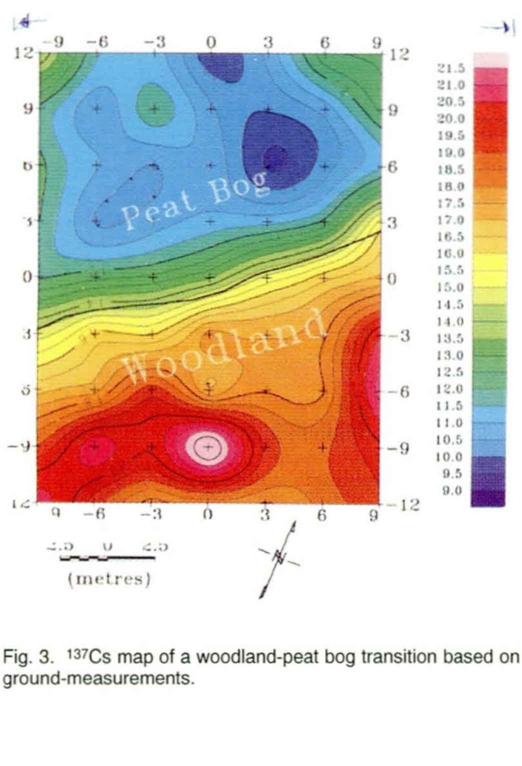

Fig. 3. ^{137}Cs map of a woodland-peat bog transition based on ground-measurements.

the evaluation of fall-out hazards. Furthermore, the speed and comprehensive nature of airborne mapping makes it a valuable tool in the early definition of fall-out patterns; in Sweden the first preliminary fall-out maps were issued only 9 days after the Chernobyl accident.

A route to man

Since the Chernobyl accident the semi-natural environment has been recognised as an important source of radiation doses to man. One of the major pathways of radio-caesium and strontium to man is the *lichen-reindeer-man* food chain. Lichens hold 5 to 10 times as much radio-caesium as vascular plants (e.g. blueberries) and are arguably the most important source of radioactive contamination in reindeer. The ecological half-life of radiation in lichens ranges between 5 to 7 years for species growing on ridge-tops and 6 to 11 years for species growing in sheltered habitats. Taking the semi-natural terrain as a whole, experience from the Chernobyl accident suggests that it would take 20 years for initial radiation levels of 20 to 40 kBq/m^2 (500-1000 CPS, Fig. 1) to return to pre-accident levels (Gaare & Staaland 1994).

At the next level in the food chain, the biological half-life of ^{137}Cs in grazing reindeer is estimated to be about 3 weeks. (Not to be confused with the ecological half-life of ^{137}Cs in reindeer meat which is 3 to 4 *years.*) The reindeer diet varies considerably through the year. In the winter, lichen constitutes 70-80% of the diet, compared with only 10 to 15% in the summer - the rest being made-up of vascular plants. Given the high concentration of radioisotopes in lichens compared with vasculars, it follows that the observed seasonal variation in radio-caesium concentration in reindeer meat is almost entirely due to variation in the lichen content of their diet.

To *predict* the radiation content of, for example, reindeer meat one must therefore have a detailed knowledge of (1) the patchy geographic distribution of fall-out, (2) the wanderings of reindeer several weeks before their slaughter and (3) their diet during that time. We have shown that airborne surveying is an effective way of mapping the fall-out (Fig. 1) so that man can intervene in the migration patterns of reindeer and hence minimise the transferral of radio-caesium into the final link of the food-chain -- man.

A significant quantity of meat from freely grazing herbivores is eaten in Scandinavia. Not just reindeer meat but meat from other deer species such as roe deer, red deer and elk (and mutton from sheep grazing semi-natural summer pastures). Elk meat alone accounts for more than one month-worth of the annual Swedish meat consumption. Even though radiation levels in elk meat are considerably lower than in reindeer meat, so much is eaten as to make it a significant source of radiation to man. Grazing herbivores aside, game birds, berries and fungi constitute pathways for the conveyance of fall-out to man.

National-scale fall-out maps and meat consumption statistics can 'smooth-out' important local variations - important for establishing the real impact of Chernobyl fall-out on man. For example, areas of high contamination can be only a few kilometres across (Fig. 1) and much depends on their chance relation to the migration routes of deer and on local eating habits. Although a great deal of research has been done in this field, particularly in Sweden, much work remains to be done before educated advice can be given to the general public on how to minimise the impact of radioactive contamination with a minimum of precaution and diet change. Detailed know-how will be an essential part of our readiness for a possible new Chernobyl-scale accident.

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