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# Gamma-Ray Emitting Radionuclides in People Living in Northern Sub Arctic Regions

*Bertil R.R. Persson*

## Abstract

In 1960 Caesium-137 activity from atmospheric nuclear weapons test was discovered in measurements at the whole body gamma-ray counting laboratory in Lund. This event initiated measurements of the Swedish Sami population, and in products from reindeer that bite lichens in the Swedish mountains. A semi-portable whole-body counter designed with a detection limit for  $^{137}\text{Cs}$  at high radiation background areas which was good enough for measuring people with high body concentration of  $^{137}\text{Cs}$ . The  $^{137}\text{Cs}$  activity concentration in Sami people increased during 1963–1965 from 300 to 600 Bq/kg body weight. Some individual males had values above 1000 Bq/kg. The catastrophic nuclear accident on the 25–26 April 1986 at the Chernobyl Nuclear Power Plant caused a massive release of fission- and neutron-activation products to the atmosphere. Already the following day the atmospheric plume of released radioactivity reached Sweden and was deposited over the central part of Sweden also in Sami populated reindeer raising districts. During 1991 and 1992 whole-body content of  $^{137}\text{Cs}$  was measured in the Sami population of northern Sweden and similar levels were found as during 1963–1965. These levels are about twice those estimated in people living in the Chernobyl contaminated area.

**Keywords:** Caesium-137, nuclear-weapons test, sodium-iodine (TI), detector, whole-body counting, Sami, Chernobyl, principal component analysis, PCA

## 1. Introduction

All people contain natural potassium of which a small fraction (0.012%) consists of the radioactive gamma emitting isotope  $^{40}\text{K}$  with the half-life of 1,258,300,000 years. A 70 kg adult human contains about 140 g of potassium in the whole body, of which 252,929,911,920,000,000,000 atoms are  $^{40}\text{K}$ . Every second a number of 4453  $^{40}\text{K}$  atoms decay in the human body, whereby emitting gamma radiation with the energy 1.46 MeV. Half of the gamma radiation is absorbed in the body while about 200 gamma ray photons per second are leaving the body. By recording these gamma rays in whole-body gamma-ray counting laboratories, the potassium content in the human body can be estimated and used in medical research.

In 1960 when people were measured for potassium at the whole body gamma-ray counting laboratory in Lund, the presence of another gamma-ray emitting

radionuclide, Caesium-137, appeared as well. This  $^{137}\text{Cs}$ -activity originates from nuclear weapons test performed in the atmosphere. Whole-body measurements of the Swedish Sami population, who consume products from reindeer that bite lichens in the Swedish mountains showed substantial content of  $^{137}\text{Cs}$ .

This chapter tells the story of how everything began and finally contributed to the termination of the extensive nuclear weapons testing in the atmosphere.

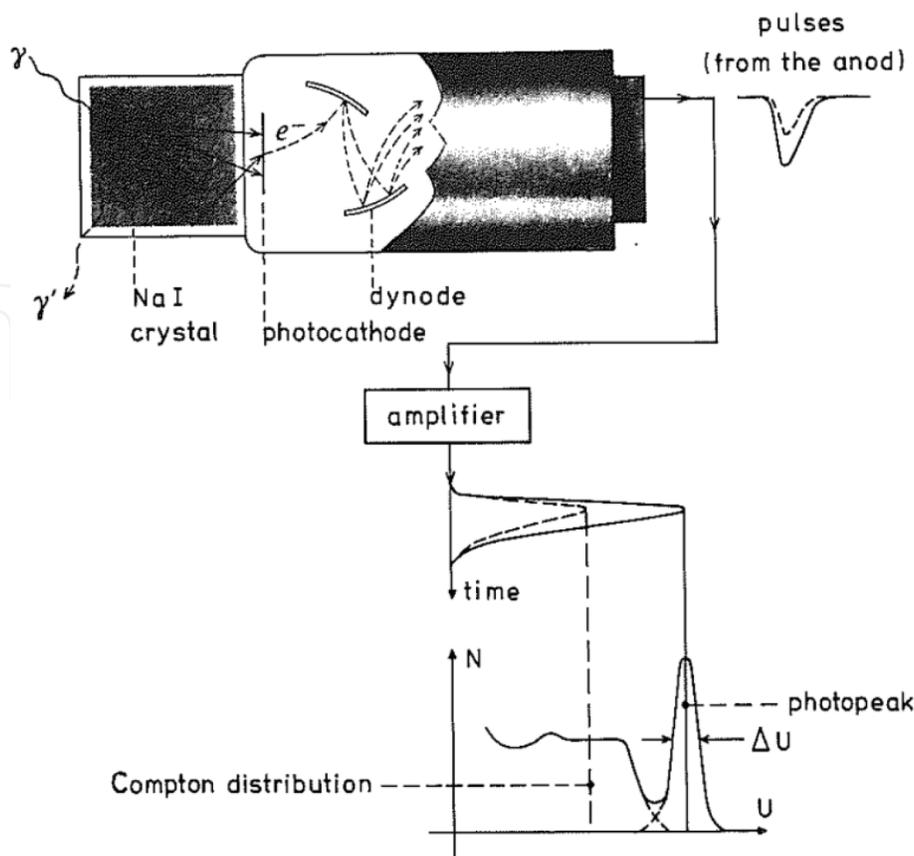
## 2. The low-level gamma ray laboratory

The research took place at the low-level gamma-ray laboratory located in the culverts of the children's hospital in Lund. There, a room was fitted with thick walls of iron plates to screen a sensitive Sodium iodide detector from ambient background radiation.

In the room, a crystal of sodium iodide, doped with thallium, was recording gamma radiation from radioactive substances in the human body. When the gamma rays hit the crystal, light flashes appear, which are captured by a photosensitive photo-anode in a photomultiplier tube which, in turn, generate electrical impulses whose magnitude are due to the energy of the gamma-rays. One of the inventors of the NaI (Tl) scintillation crystal was professor Sven Johansson at the Department of Nuclear Physics at Lund University. Recently the first small crystals he produced was found when tidying up at the Physics department in Lund.

**Figure 1** shows the principle of how the sodium-iodine (Tl) detector record gamma-rays.

The original idea for the gamma-ray laboratory was to use the equipment to record the most common natural radioactive substance in the human body, potassium-40, for medical research [2]. As a quality control, the collaborators at the



**Figure 1.**  
The principle of how a sodium-iodine (Tl) detector record gamma-rays [1].

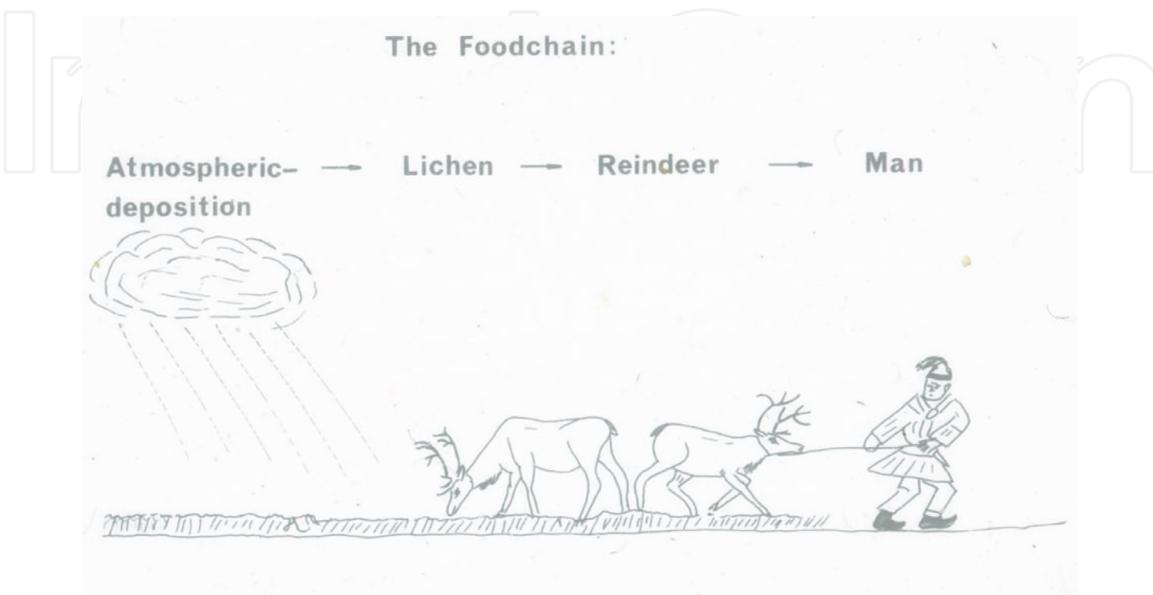
gamma-ray laboratory regularly measuring their potassium content. One collaborator was from Norway, and in 1960, when he returned from his vacation in Norway, a broad peak indicating gamma radiation from  $^{137}\text{Cs}$  appeared in the whole-body spectrum. He told that he had been eating cheese produced from sheep's baiting in the Norwegian mountains. The cheese contained high levels of radioactive caesium-137 released to the atmosphere by the United States nuclear weapons testing in the Pacific.

A similar relationship would exist in the reindeer raising Sami people who live in Northern Sweden. The transfer of atmospheric fallout through the food-chain Lichen-reindeer-man shown in **Figure 2**. Another collaborator Calle Carlsson (whom later on became a professor in Radiation Physics at Linköping University) was sent to Northern Sweden to collect samples. The piece of reindeer meat he brought from Northern Sweden to Lund was found to contain just over 1000 Bq of  $^{137}\text{Cs}$  per kg. That was quite a high level compared to the  $^{137}\text{Cs}$  levels in ordinary beef from Southern Sweden which contained about 4 Bq per kg. It became apparent that the Sami people should have high levels of caesium-137 due to the food chain lichen-reindeer-man as shown in **Figure 2**.

At the beginning of May 1961 encouraged by the results of Calle Carlsson's exploration, Kurt Lidén invited two Sami people from Lapland ( $67^\circ\text{N}$ ) to Lund. They measured at the gamma-ray laboratory, and it discovered that they had a caesium-137 content which was much higher than earlier was found in the Norwegian collaborator.

A research program was arranged to study the Caesium-137 activity in the Swedish Sami population, and in products from reindeer that bite lichens in the Swedish mountains. I participated in the annual expeditions to the Sami villages from Funäsdalen up to Karesuando at the Northern Swedish border to Finland. A mobile whole body counter laboratory was built on a military bus, lent by the National Defence Research department in Stockholm (FOA). In the middle of the bus was placed a lead-protected whole body gauge with a large NaI(Tl) crystal which was 5 inch in diameter and 4 inches thick.

Yngve Naversten was responsible for the design of the semi-portable whole-body counter [4]. The 42 cm wide chair arrangement was similar to the stationary whole-body counter at Lund and shielded was lead bricks. Since the  $^{137}\text{Cs}$  body



**Figure 2.**  
*A sketch illustrating the food chain lichen-reindeer-man drawn by the author's colleague and friend MD Torsten Landberg (d. 2015) as a dedication to my thesis 1970 [3].*

burdens in the Sami population was in the order of 4 kBq the background shielding was not critical.

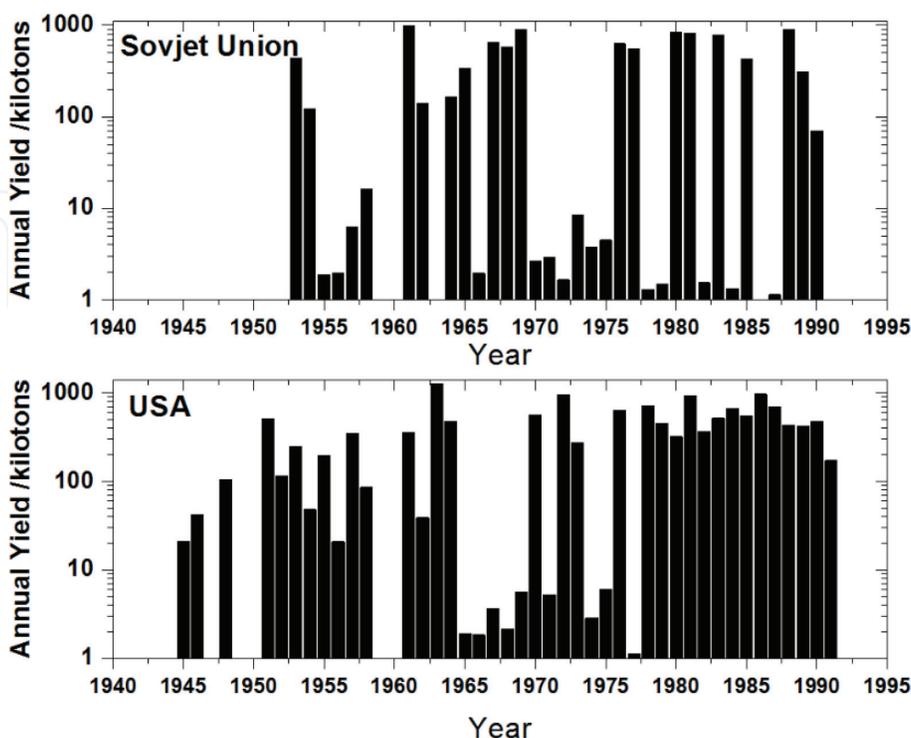
The sensitivity of the NaI(Tl) detector for  $^{137}\text{Cs}$  and potassium ( $^{40}\text{K}$ ) in a subject of 70 kg body weight, is 0.048 counts per minute per Becquerel (Bq)  $^{137}\text{Cs}$ , and 0.18 counts per minute per gram potassium.

The detection limit for  $^{137}\text{Cs}$  in people at the high radiation background level at Jokkmokk, corresponded to about 14 Bq  $^{137}\text{Cs}/\text{kg}$ , which is good enough for their people, with average body concentration of about 55 Bq  $^{137}\text{Cs}/\text{kg}$ . In Lund, however, the detection limit corresponded to about 10 Bq/kg which is too low for people in the control group with body concentration of about 12 Bq/kg. They measured in the iron shielded room with detection limit corresponding to about 3 Bq/kg.

### 3. Atmospheric nuclear weapons testing

The origin of  $^{137}\text{Cs}$  in the environment was the atmospheric nuclear weapons tests started by the development of the atomic bombs, which in 1945 fell over Hiroshima and Nagasaki. After World War 2 the developing and testing of nuclear weapons continued by both the USA and the Soviet Union. A summary of the annual Nuclear weapon explosion yield by the USA and the USSR up to 1990 given in **Figure 3** in units of an equivalent amount (kilotons, kt) of the conventional explosive tri-nitro-toluene (TNT) [5, 6].

A Limited Test Ban Treaty, pledging to refrain from testing nuclear weapons in the atmosphere, underwater, or in outer space, was signed by the three (UK, US, Soviet Union) of the four nations developing nuclear weapons in 1963. The fourth nation France continued atmospheric nuclear weapon testing until 1974. Later China started to develop their nuclear weapons and continued with atmospheric testing until 1980.



**Figure 3.** Annual nuclear weapon explosion yield by the USA and the USSR up to 1990, expressed in an equivalent amount (kilotons, kt) of the conventional explosive tri-nitro-toluene (TNT) [5, 6].

Calle Carlsson declared in his death row over Kurt Lidén:

*“I am convinced that the high radioactivity of reindeer raising people in The Northern Sub Arctic regions accelerated and actually forced the Test Prohibition Agreement pledging to refrain from testing nuclear weapons in the atmosphere” [7].*

After the Treaty in 1963 to refrain from testing nuclear weapons in the atmosphere, United States continued to perform underground nuclear weapons testing until 1992 (its last nuclear test), and so did the Soviet Union until 1990.

In the explosion of a nuclear weapon, its load of uranium or plutonium splits into two lighter nuclei and release an enormous amount of energy, a process called fission. The most long-lived gamma-ray emitting lighter element released is  $^{137}\text{Cs}$  with a half-life of about 30.2 years. During the period of atmospheric testing,  $^{137}\text{Cs}$  was spread in the atmosphere and deposited as nuclear fallout and transferred to plants, animals, and man all over the world.

#### 4. Reference groups for whole-body measurements

In January 1960 a reference group for whole-body measurements which comprised of people of different age and both sexes was established in Lund. Since 1964 everyone in this group could not regularly participate in the whole-body measurements, and two utterly new reference groups started—one with 33 school-children aged between 14 and 15 years, from a school in Lund. The other group included 14 women and 20 men who worked nearby in a local factory. Three times a year, these groups experienced whole-body measurements of  $^{137}\text{Cs}$  originated from the fallout of atmospheric nuclear weapons tests and natural  $^{40}\text{K}$  for estimation of the total potassium content in the body. Since both the element Caesium (Cs) and potassium (K) belong to alkali metals, the first group in the periodic system, their physiological behaviour was believed to be highly correlated. Thus the  $^{137}\text{Cs}$ -body content, is sometimes indicated as the  $^{137}\text{Cs}/\text{K}$  ratio in Bq/gK. **Figure 4** displays the time variation of the  $^{137}\text{Cs}/\text{K}$  ratio Bq/gK in the control groups at Lund, with the total yields of atmospheric nuclear weapons testing derived from **Figure 3** at the bottom.

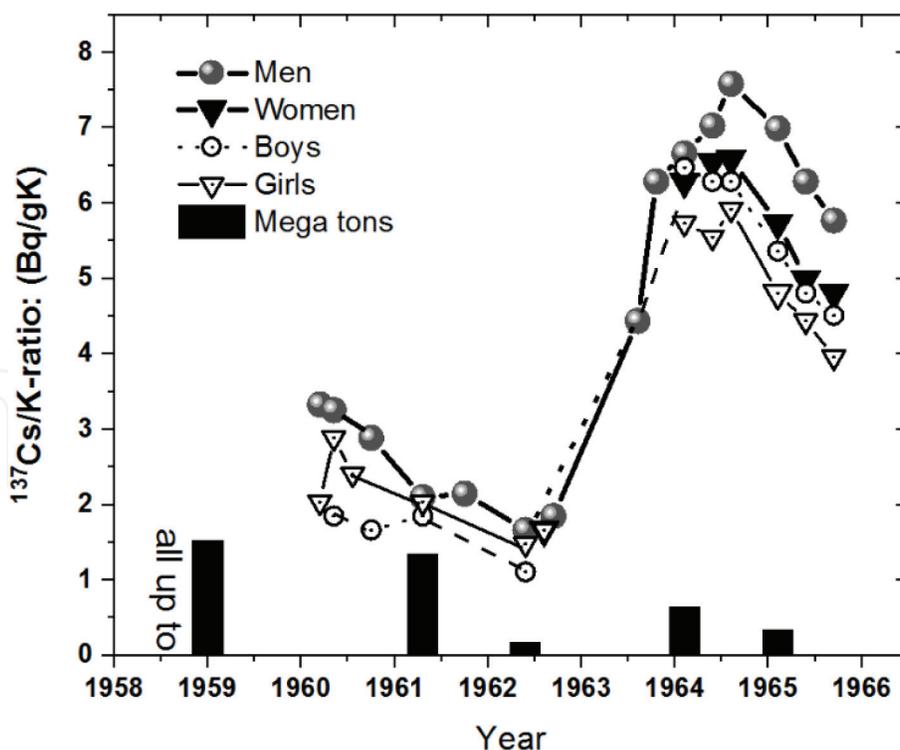
In 1964, a comprehensive survey of school children aged 14–15 conducted at five different places, in different parts of Sweden. The selection criteria were as follow.

- That the students should have lived in the resort for at least 1 year.
- That they did not belong to any Same families.

The results given in **Table 1** are  $^{137}\text{Cs}$  levels in March 1964 of non-Sami school-children at the age of 14–15 years.

The activity concentration of  $^{137}\text{Cs}$  in the Nässjö group was slightly higher than the Lund group, which may be due to higher concentrations of  $^{137}\text{Cs}$  in locally produced foods. The high levels in Jokkmokk and Funäsdalen are probably due to consumption of reindeer products. While the unexpectedly low values in Lycksele may be that reindeer products are easier available in Jokkmokk and Funäsdalen than in Lycksele.

A partial least square modelling of the activity concentration of  $^{137}\text{Cs}$  given in **Table 1**, with position(°N,°E), age (a), body-weight ( $\text{kg}_{\text{BW}}$ ) and potassium concentration ( $\text{gK}/\text{kg}_{\text{BW}}$ ) as dependent variables was performed for females (FM) and



**Figure 4.** Time variation of the  $^{137}\text{Cs}/\text{K}$  ratio Bq/gK in the control groups at Lund. The columns at the bottom represent the yields of atmospheric nuclear weapons testing.

Location	Weight	Weight	$^{137}\text{Cs}$	$^{137}\text{Cs}$	K	K
Place	M kg	FM kg	M Bq/kg	FM Bq/kg	M gK/kg	FM gK/kg
Jokkmokk AJ	44	43	60.13	50.34	1.68	1.75
Lycksele ALy	44.5	42	21.53	17.44	1.59	1.61
Funäsdalen AF	41	45.5	45.39	53.26	1.69	1.53
Nässjö AN	45	43.5	15.62	13.78	1.74	1.68
Lund AN	46.5	48	12.89	10.18	2.01	1.84

**Table 1.** The  $^{137}\text{Cs}$ -concentration, Bq per kg body weight (Bq/kg), the potassium concentration in g per kg body weight gK/kg measured 1964 in male (M) and female (FM) school children (age about 14) at the various locations in Sweden and who did not belong to any Sami families.

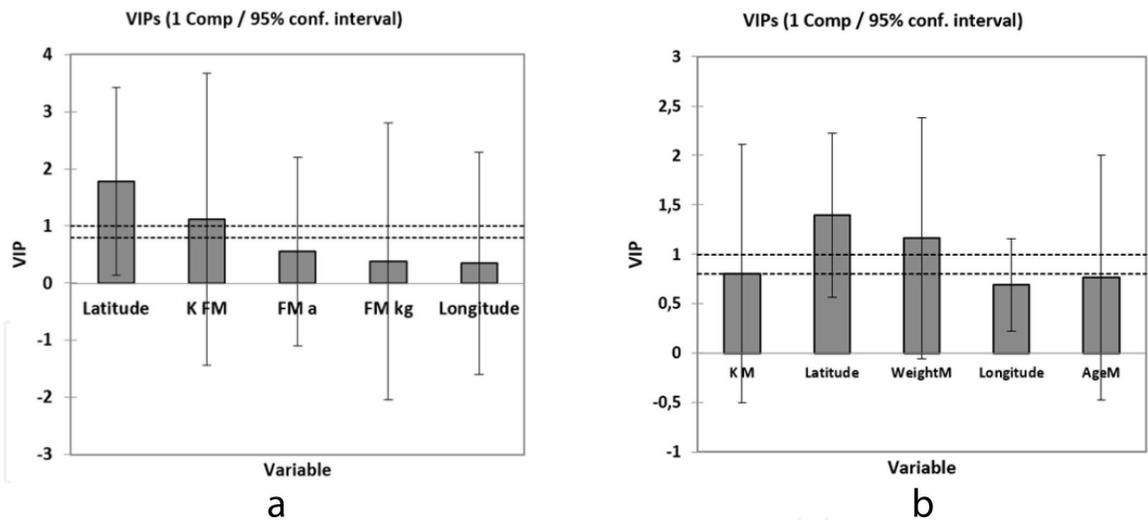
males (M) respectively. The equations for prediction of  $^{137}\text{Cs}$  activity concentration in Bq per kg body weight are given below for females and males respectively.

$$^{137}\text{Cs}(\text{Bq}/\text{kg}_{\text{BW}}\text{FM}) = -81.6 + 1.366 \times (^\circ\text{N}) + 0.379 \times (^\circ\text{E}) + 7.13 \times (a) - 0.569 \times (\text{kg}_{\text{BW}}) - 32.88 \times (\text{gK}/\text{kg}_{\text{BW}}) \quad (1)$$

$$R^2 = 0.32,$$

$$^{137}\text{Cs}(\text{Bq}/\text{kg}_{\text{BW}}\text{M}) = -169.8 + 3.796 \times (^\circ\text{N}) + 1.584 \times (^\circ\text{E}) + 5.843 \times (a) - 7.623 \times (\text{kg}_{\text{BW}}) - 113.0 \times (\text{gK}/\text{kg}_{\text{BW}}) \quad (2)$$

$$R^2 = 0.88.$$



**Figure 5.** Variable importance in the projection of the  $^{137}\text{Cs}$  prediction equations for (a) female and (b) male.

Variable importance in the projection (VIP) of the  $^{137}\text{Cs}$  prediction equations (Eqs. (1) and (2)) are given in **Figure 5a** for female and **Figure 5b** for male respectively. The most important variables for female are latitude and potassium concentration, while for male, the body weight is of great importance as well.

## 5. Whole-body measurement reference groups from the rural population in northern Sweden

Other whole-body measurement reference groups established at different places in Sweden with farmers, forest workers and other heavy working people with their family members. The aim was to compare the body activity of  $^{137}\text{Cs}$  in the Sami people with other groups of people,

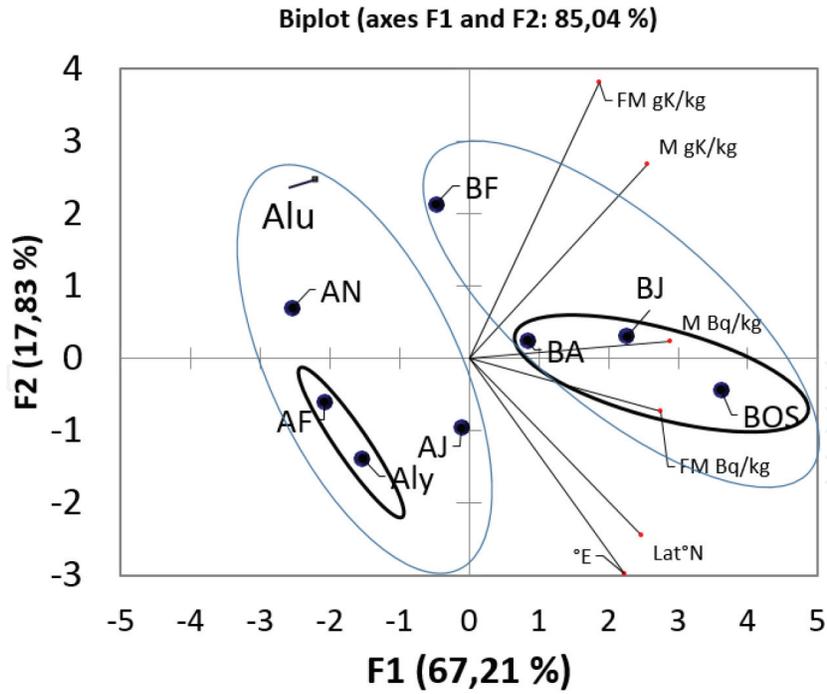
As seen from **Table 2** the activity concentration of  $^{137}\text{Cs}$  in females are about half of the corresponding values in males.

A principal component analysis (PCA) was performed with the variables  $^{137}\text{Cs}$ -concentration ( $\text{Bq}/\text{kg}_{\text{BW}}$ ), potassium concentration ( $\text{gK}/\text{kg}_{\text{BW}}$ ), and position ( $^{\circ}\text{N}$ ,  $^{\circ}\text{E}$ ). The results shown in **Figure 6** are those labelled A from **Table 1**, and that labelled B are from **Table 2**.

As seen in **Figure 6** the reference groups are well separated, with Funäsdalen ( $62.50^{\circ}\text{N}$ ,  $12.50^{\circ}\text{E}$ ) and Lycksele ( $64.6^{\circ}\text{N}$ ,  $18.7^{\circ}\text{E}$ ) as a subgroup in A and Övre Soppero ( $68.09^{\circ}\text{N}$ ,  $21.70^{\circ}\text{E}$ ), Jokkmokk ( $66.60^{\circ}\text{N}$ ,  $19.80^{\circ}\text{E}$ ) and Arvidsjaur ( $65.66^{\circ}\text{N}$ ,  $19.47^{\circ}\text{E}$ ) as a subgroup in B, and the two groups in Jokkmokk separated.

Location	Male	Female	Male	Female
	$^{137}\text{Cs}$ Bq/kg <sub>BW</sub>	$^{137}\text{Cs}$ Bq/kg <sub>BW</sub>	gK/kg <sub>BW</sub>	gK/kg <sub>BW</sub>
Övre Soppero BOS	273.8	166.5	2.3	1.8
Jokkmokk BJ	188.7	103.2	2.4	1.8
Arvidsjaur BA	92.1	57.0	2.2	1.8
Funäsdalen BF	80.7	34.4	2.1	1.9

**Table 2.** The  $^{137}\text{Cs}$ -concentration, Bq per kg body weight ( $\text{Bq}/\text{kg}$ ), the potassium concentration in gK per kg body weight  $\text{gK}/\text{kg}_{\text{BW}}$  in the reference groups from the rural population measured 1965 at various places in northern Sweden.



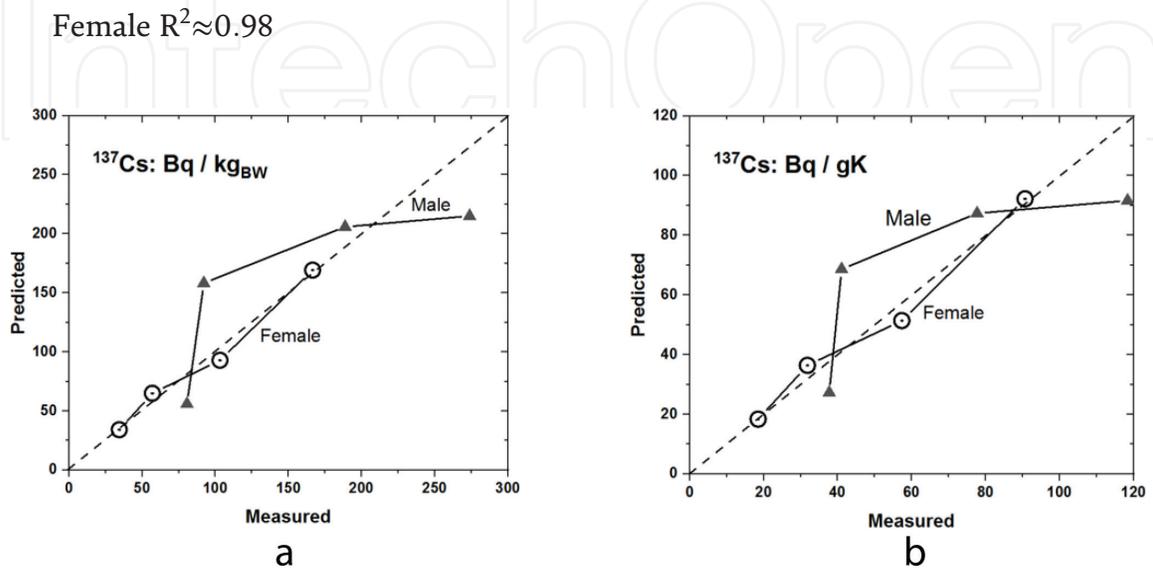
**Figure 6.** Biplot of the results of principal component analysis (PCA) of the variables, latitude, longitude,  $^{137}\text{Cs}$ -concentration, and potassium concentration **Table 1** Labelled A and in **Table 2** labelled B.

A partial least squares modelling of the activity concentration of  $^{137}\text{Cs}$  given in **Table 2**, with position ( $^{\circ}\text{N}$ ,  $^{\circ}\text{E}$ ), and potassium concentration ( $\text{gK}/\text{kg}_{\text{BW}}$ ) as dependent variables was performed for FM and M respectively. The equations for prediction of  $^{137}\text{Cs}$  activity concentration in Bq per kg body weight are given below for females and males respectively.

Male  $R^2 \approx 0.6$

$$^{137}\text{Cs} (\text{Bq}/\text{gK}) = -474.743 + 5.109 \times (^{\circ}\text{N}) + 2.550 \times (^{\circ}\text{E}) + 70.549 \times (\text{gK}/\text{kg}_{\text{BW}}) \quad (3)$$

$$^{137}\text{Cs} (\text{Bq}/\text{kg}_{\text{BW}}) = -1189.764 + 12.436 \times (^{\circ}\text{N}) + 6.253 \times (^{\circ}\text{E}) + 182.643 \times (\text{gK}/\text{kg}_{\text{BW}}) \quad (4)$$



**Figure 7.** (a) Predicted versus the measured  $^{137}\text{Cs}$  body concentration in  $\text{Bq}/\text{kg}$  body weight. (b) Predicted versus the measured value of the ratio of  $^{137}\text{Cs}$  activity (Bq) and potassium content (gK).

$$^{137}\text{Cs} \text{ (Bq/gK)} = -1614.243 + 9.307 \times (^\circ\text{N}) + 3.737 \times (^\circ\text{E}) + 539.87 \times (\text{gK/kg}_{\text{BW}}) \quad (5)$$

$$^{137}\text{Cs}(\text{Bq/kg}_{\text{BW}}) = -3034.159 + 17.152 \times (^\circ\text{N}) + 6.855 \times (^\circ\text{E}) + 1027.201 \times (\text{gK/kg}_{\text{BW}}) \quad (6)$$

The predicted values from these equations are plotted against the measured values from **Table 2** and displayed in **Figure 7b**.

The large spread in the values for males is probably due to large variations in body-weight and potassium content. While these quantities are less variable for the female group.

## 6. Whole body measurements of reindeer raising Sami

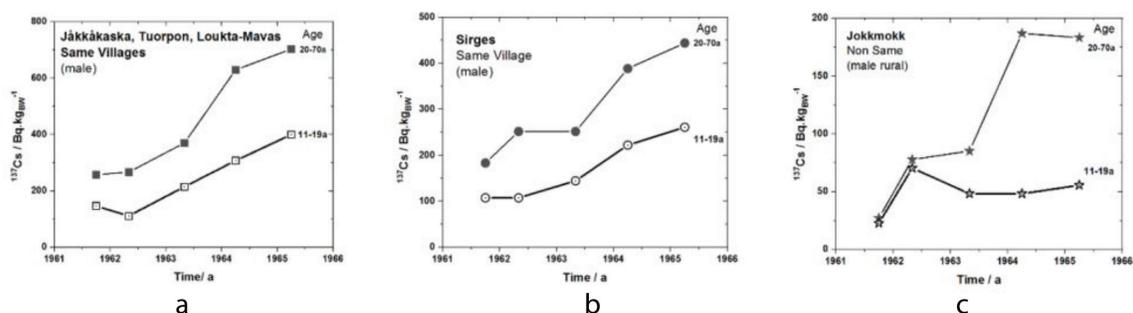
The high accumulation of fallout from nuclear bomb tests in the food chain lichen - reindeer meat—man (**Figure 2**), and large consumption of reindeer meat result in substantially increased  $^{137}\text{Cs}$  levels in reindeer-raising Sami.

This relationship was explored during 1961 and 1962 by measurements of the  $^{137}\text{Cs}$  body burden of the Same population in Jokkmokk. The Whole-body measurement program extended in 1963 to some other places in the reindeer-raising district. The results of these measurements which are summarised below have previously published by Kurt Lidén and collaborators [8–10].

**Figure 8** shows the activity concentration (Bq/kg) of  $^{137}\text{Cs}$  during the period 1961–1965 in old and young male Sami people in mountain Sami villages Jåkkåaska, Tuorpon, Loukta-Mavas and Sirges (previously named Sirkas), as well in non-Sami rural people in the Jokkmokk district. The  $^{137}\text{Cs}$  activity concentration increased rapidly between 1963 and 1964 due to the extensive atmospheric nuclear weapon testing in 1961. In 1965, average levels in the range of about 200–700 Bq/kg<sub>BW</sub> were reached, with some individual males above 1000 Bq/kg<sub>BW</sub>.

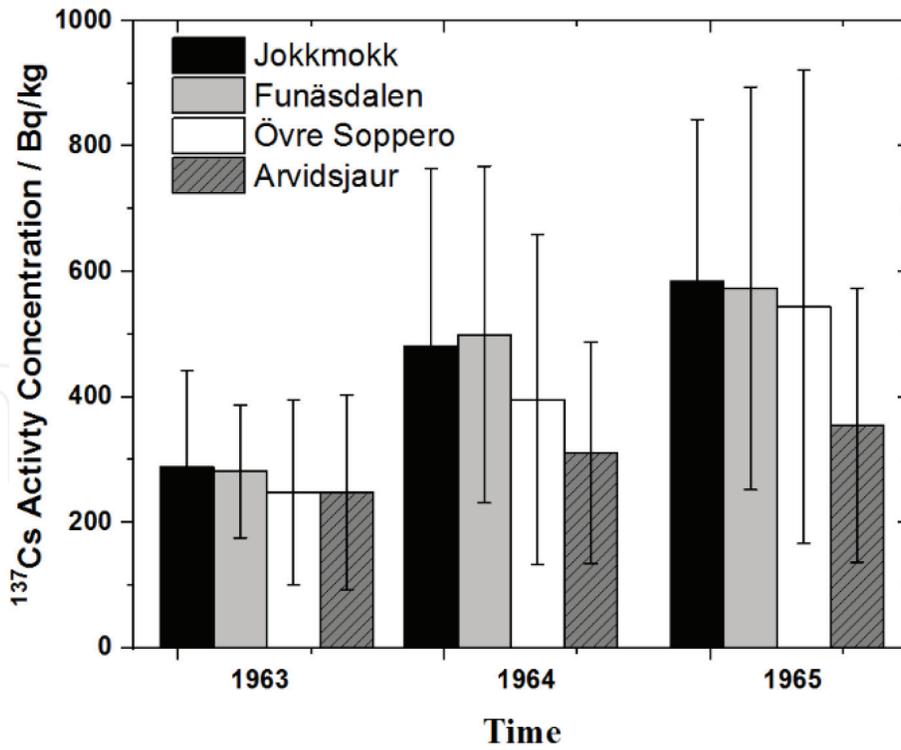
In **Figure 8** presents the variation of the  $^{137}\text{Cs}$  activity concentration during the period September 1961–March 1965 for male elderly (age 20–70a) and youngster (age 11–19a) for both the Sami people and the control group at Jokkmokk. Between 1964 and 1965, the older group in rural non-Sami people in Jokkmokk district has a lower level of  $^{137}\text{Cs}$  than the group in mountain Sami village Sirges (Si), which in turn was 40% lower than the groups Jåkkåaska, Tuorpon, and Luokta-Mavas (JA). These differences are even higher for the younger group.

The activity concentration (Bq/kg) of  $^{137}\text{Cs}$  during the period 1961–1965 in old and young male Sami people in various Sami villages (a and b) and rural non-Sami people in Jokkmokk district (c).



**Figure 8.**

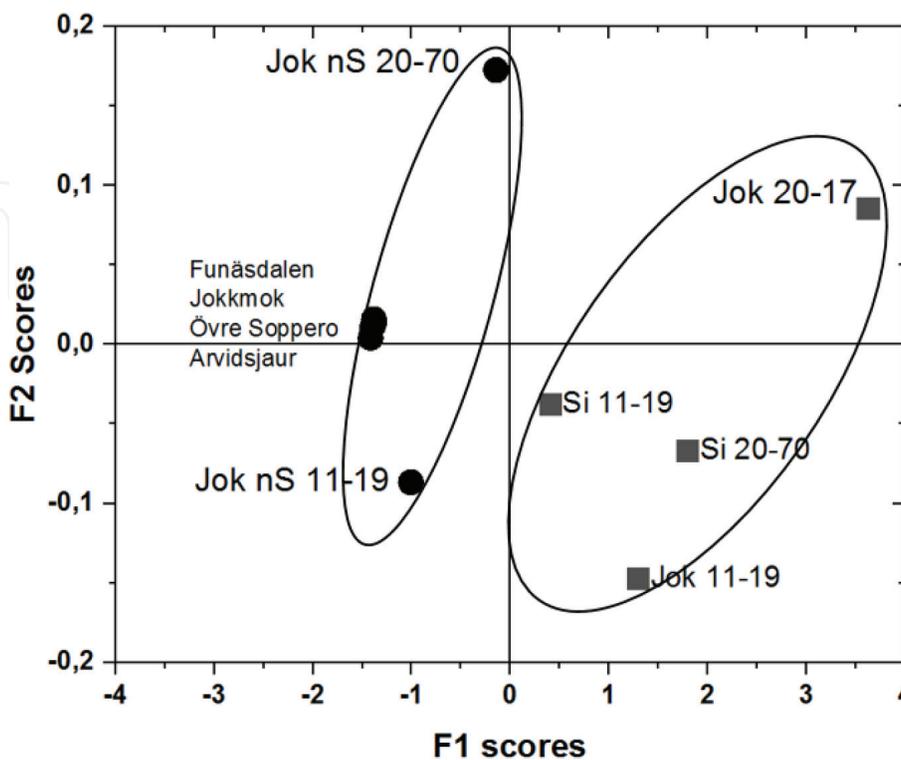
(a) Mountain Sami villages people Jåkkåaska, Tuorpon, and Loukta-Mavas. (b) Mountain Sami village Sirges. (c) Rural non-Sami in Jokkmokk district.



**Figure 9.**

The average values and the estimated standard deviation (SD) given for  $^{137}\text{Cs}$  activity concentration during 1963–1965 in Sami people in four different reindeer raising districts. The Arvidsjaur district comprises three groups from forest villages. The other are from the mountain Sami villages in Jokkmokk municipality (Jäkkäkaska, Tuorpon, and Sirges) Funäsdalen and Övre Soppero.

Not shown in the figure, the differences in  $^{137}\text{Cs}$  levels for the 20–70 age group of women in Sirges was lower than in JA with 10% in 1964 and 25% in 1965. The girls (age 11–19a) have about equal levels in 1964 in Sirges and JA. However, in 1965 the levels in Sirges was about 20% lower than in JA [10].



**Figure 10.**

The result of PCA analysis of all whole body measurements during 1963–1965.

In **Figure 9** are given the  $^{137}\text{Cs}$  activity concentration during 1963–1965 in Sami people from four different districts. The Arvidsjaur district comprises three groups from forest villages, and the others are from mountain Sami villages in Jokkmokk municipality (Jåkkåkaska, Tuorpon, and Sirges), Funäsdalen and Övre Soppero. The average  $^{137}\text{Cs}$  activity concentration during 1963–1965 increased from 300 to 600 Bq/kg body weight in Sami people living in mountain villages.

Although some individuals in 1965 showed  $^{137}\text{Cs}$  levels above 1000 Bq per kg body weight, they expressed no fear about these high levels. Instead, individuals with high levels were respected and honoured, because high levels of radioactivity were a sign of hard and dedicated work with the reindeer.

**Figure 10** shows the principal component analysis (PCA) results of the  $^{137}\text{Cs}$  activity concentration during 1963–1965 in Saami people in four different districts displayed in **Figure 9** and the control groups given in **Table 2**. **Figure 10** clearly shows the difference between the Sami people and the people in the control groups. The main difference between the two populations is due to the higher consumption of meat and other products of reindeer by the Sami people.

## 7. Radiation dose contribution and health aspects

The annual radiation dose contribution to an adult person of a constant  $^{137}\text{Cs}$  body-concentration of 1 Bq/kg<sub>BW</sub> is estimated to be about 2.2  $\mu\text{Sv}$  per year. During 1995 the male reindeer-raising mountain Sami with an average  $^{137}\text{Cs}$  body-concentration of about 500 Bq/kg received about 1.1 mSv per year.

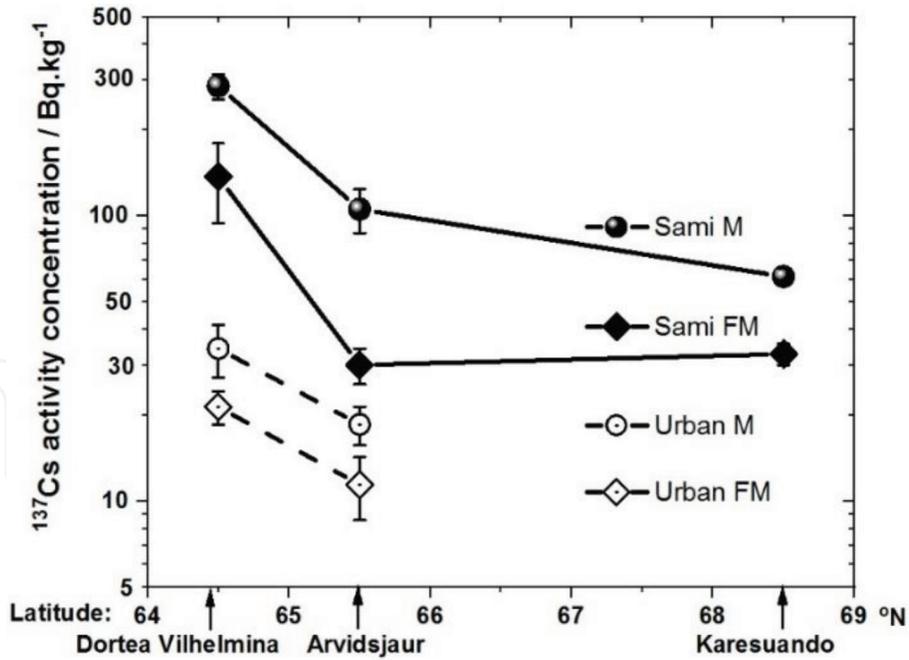
The radiation-dose contribution to people who eat many foods with high concentrations of caesium-137 is estimated to be about 1–2 mSv/year. However, the radiation dose from a large intake of reindeer meat is also due to naturally occurring polonium-210 [11]. The total radiation dose from all environmental sources is estimated to be about 3–4 mSv/ year.

## 8. The Chernobyl accident

A catastrophic nuclear accident occurred on the 25–26 April 1986 in the No. 4 light water graphite moderated reactor at the Chernobyl Nuclear Power Plant near the now-abandoned town of Pripjat, in northern Ukraine, approximately 104 km north of Kiev. During several days the accident caused a large release of fission- and neutron-activation products to the atmosphere. Already the following day the atmospheric plume of released radioactivity reached Sweden. During April 28th a heavy rainfall deposited the radioactive dust in the plume over the central part of Sweden, leading to high surface contamination of  $^{137}\text{Cs}$  ( $>100 \text{ kBq}\cdot\text{m}^{-2}$ ) in Sami populated reindeer raising districts.

During 1991 and 1992 whole-body content of  $^{137}\text{Cs}$  was measured in the Sami population of northern Sweden. The Radiation Physics department at Umeå University arranged measurements in three areas with various levels of  $^{137}\text{Cs}$  deposition [12–14].

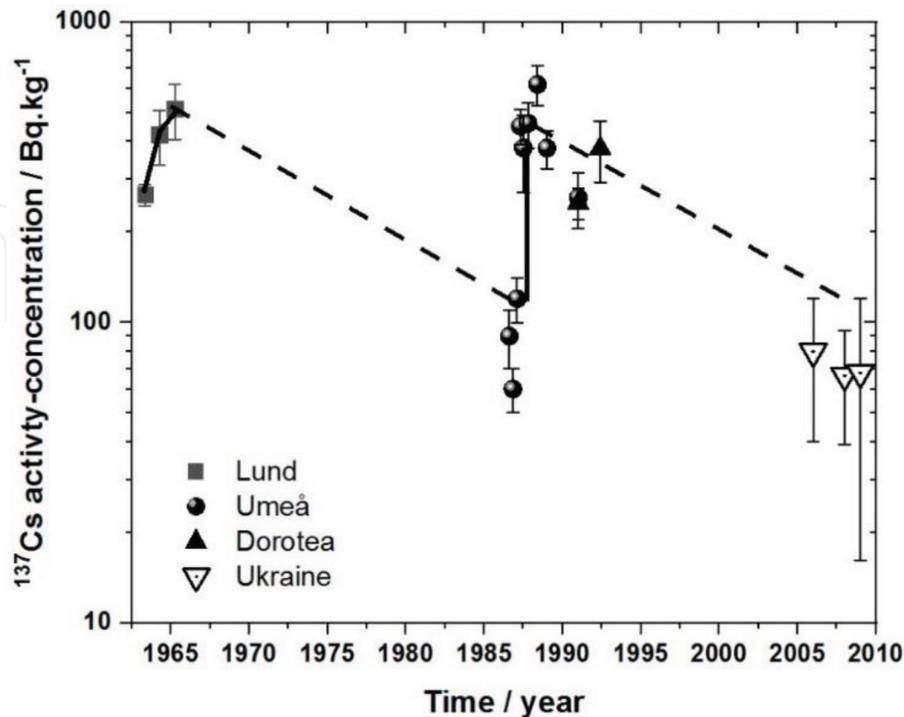
Two groups of individuals are randomly chosen, of which one group representing the urban population of the area, and the other the members of the Sami communities. The average whole-body content of  $^{137}\text{Cs}$  in the general population varied between 1.1 and 2.0 kBq, and for the Sami population between 3.4 and 25 kBq. **Figure 11** shows the average  $^{137}\text{Cs}$  activity concentration in the Sami and urban population in districts of various contamination level. In the most contaminated areas, there were some individuals with levels above 1000 Bq/kgBW.



**Figure 11.**  
The average  $^{137}\text{Cs}$  activity concentration in the Sami and urban population in various districts [12].

## 9. Discussion and conclusion

**Figure 12** displays the results of whole-body measurements of  $^{137}\text{Cs}$  in the Swedish Sami population from nuclear weapons fallout during the 1960th and the Chernobyl fallout after the 1986 accident. For comparison, the 2006–2010 results of reported whole-body measurements of people living in the vicinity of Chernobyl are



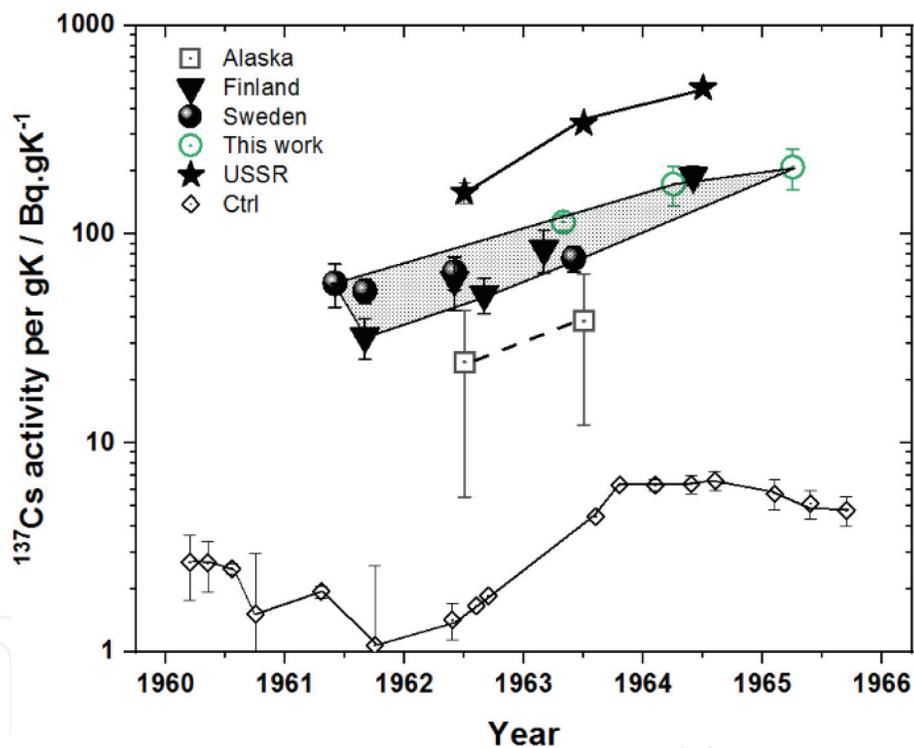
**Figure 12.**  
Summary of the  $^{137}\text{Cs}$  activity concentration in the Swedish Sami population measured by the research teams from Lund and Umeå universities. The  $^{137}\text{Cs}$  activity concentration in people living in the vicinity of Chernobyl in Ukraine, (symbol  $\Delta$  in the figure) derives from published data [15].

also given in **Figure 12** [15]. The extrapolated value of whole-body measurements of  $^{137}\text{Cs}$  in the Swedish Sami population from 1994 to 2007 is about twice the Ukraine value. The Sami population living in Northern Sub Arctic regions is primarily affected by atmospheric deposition of the gamma emitting radionuclide  $^{137}\text{Cs}$ .

Enhanced  $^{137}\text{Cs}$  concentrations in reindeer raising people has also been reported from in Finland and Russia [16]. Eskimos and other inhabitants in Alaska consuming caribou (wild reindeer) show enhanced  $^{137}\text{Cs}$  body concentrations [17].

In **Figure 13** is displayed values of the ratio of  $^{137}\text{Cs}$  body activity (Bq) and potassium content (gK) in people living in Northern Sub Arctic regions and consuming reindeer or caribou (Alaska). The values in **Figure 13** derive from this work and **Table 3** in the 1964 Report of the United Nations Scientific Committee on the effects of atomic radiation [18].

The discovery of the massive increase of  $^{137}\text{Cs}$  bodily activity (Bq) in the Sami population in Sweden and Finland and closely related populations of the Soviet Union and its steady increase in the 1960's actually forced the United States, United Kingdom and Soviet Union test bans in 1964 promising to refrain from test nuclear weapons in the atmosphere [7].



**Figure 13.** The ratio of  $^{137}\text{Cs}$  total body activity (Bq) and potassium content (gK) in people living in northern Sub Arctic regions consuming reindeer or caribou (Alaska). The lower curve is the average of the control groups in Lund [8].

Time	Jokkmokk	Funäsdalen	Ö Soppero	Arvidsjaur	AVE $\pm$ SD
1963.33	0.6 $\pm$ 0.3	0.6 $\pm$ 0.2	0.5 $\pm$ 0.3	0.5 $\pm$ 0.3	0.59 $\pm$ 0.05
1964.25	1.1 $\pm$ 0.6	1.1 $\pm$ 0.6	0.9 $\pm$ 0.6	0.7 $\pm$ 0.4	0.93 $\pm$ 0.19
1965.25	1.3 $\pm$ 0.6	1.3 $\pm$ 0.7	1.2 $\pm$ 0.8	0.8 $\pm$ 0.5	1.13 $\pm$ 0.24

**Table 3.** The estimated annual radiation dose contribution to adults (mSv per year) of  $^{137}\text{Cs}$  body-content at various places in Sweden and averages (AVE) with standard deviation ( $\pm$ SD) in the last column.

## **Acknowledgements**

This chapter dedicates to professor emeritus Calle Carlsson on his 95th year of age, to honour his pioneering efforts in the project to measure the radioactivity of the Sami population living in Northern Sub Arctic regions, that forced the Test Prohibition Agreement pledging to refrain from testing nuclear weapons in the atmosphere.

## **Conflict of interest**

The author declares no conflicts of interests.

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