FINAL REPORT

FOR THE PROJECT

RADIOACTIVE FOODCHAINS IN THE SUBARCTIC ENVIRONMENT. ***

SEPTEMBER 1979

JORMA K. MIETTINEN

DEPARTMENT OF RADIOCHEMISTRY
UNIVERSITY OF HELSINKI

DISCLAIMER

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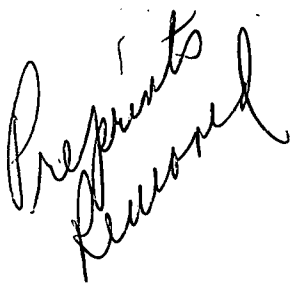

FINAL REPORT

INTRODUCTION

This research project originally started 1964, but this report will be mainly concentrated on results obtained during the last three years. The earlier results have been covered by annual and triannual reports. Nevertheless, they will be also briefly summarized in this report, in its first, "historical" chapter. In earlier years attention was devoted to fission products (1964-72) and natural radionuclides (1966-68) of the fallout and the foodchains leading to their enrichment into man. In the years 1973-75 our attention was directed more to studies of transuranium nuclides in the same foodchains.

Reindeer and lichen were first in the focus regarding transfer of $^{239,240}Pu$. During the last three years plutonium in human tissues and ^{241}Am in the environment have also become into the focus of our research.

1. Studies of fission product foodchains in 1964-69 under this project

During this period the behaviour in the subarctic environment of the fission products ^{137}Cs, ^{90}Sr and ^{55}Fe originating from atmospheric nuclear tests was studied in great detail and the foodchains enriching these nuclides fully elucidated.

They are: 1) lichen - reindeer - man;
2) lake water - plankton - fish - man;
3) sea water - fish - man (for ^{55}Fe);
4) grass(sedge) - cow(milk) - man.

A broad view on the enrichment of ^{137}Cs to reindeer and Lapps was obtained already in 1965 (Publ. No. 1)*. The most efficient foodchain for this nuclide was: lichen-reindeer meat-man. In those households in

* References to papers published under this project are cited here with a No. A list of these papers follows this Report (see p. 24).

which the cattle was grazing on sedge and horsetail which grew wild on flooded riverbanks cow's milk also was about 10 times higher on ^{137}Cs than in southern Finland (non-flooded pastures, mostly cultivated). In these families milk gave a significant contribution in the years 1963-65 (5-15%). Fresh water fish, particularly pike, also contained much ^{137}Cs in these years, up to 1/3 of that in reindeer meat, and gave ca. 15 % of the total dietary intake of ^{137}Cs in fisher families consuming a lot of fish. In 1966 (paper No. 2) it was shown that while the maximal ^{137}Cs concentrations in the annual fallout, in lichen and in reindeer meat were reached in 1964, in Lapps they were reached one year later, 1965. The average body burden of ^{137}Cs in adult Finnish Lapps (both sexes) was then 10 nCi/gK or about 50 times that in southern Finns. In March 1966 a 15 per cent decrease from the values measured in the previous spring was observed. This was the first year the body burdens began to decrease. It was clear then that in future the body burdens would continue to decrease if new major atmospheric tests would not be carried out (paper No. 2).

As for ^{90}Sr, careful dietary studies showed that the Lapps obtained it mainly through cow's milk and reindeer meat. Since ^{90}Sr is mainly concentrated in bones the total intake by Lapps is only 2 or 3 times higher than that by southern Finns (or Europeans in general).

However, the Skolt Lapps (a small group of Finnish Lapps ethnically slightly different from other Lapps) were exceptional because their diet contained only sparingly calcium, ca. 400 mg/d while 1 g/d is considered to be a recommendable minimum requirement by man. It was therefore concluded that the ^{90}Sr content of their bones could be up to tenfold in comparison to other Finns. It has not been possible to get bone samples from Skolt Lapps, so far - they are living in a remote area near the eastern border and their number is too small. However, it has been shown in a corresponding group of reindeer herders in the Soviet Union by Prof. P. Ramzayev (Institute of Radiation Hygiene, Leningrad; personal information) that some Soviet herders have ca. 10 times higher ^{90}Sr body burdens than the average population because of great consumption of bone marrow of reindeer.

In 1966 it became possible to us to take urine and blood samples from 18 Skolt Lapps and 18 southern Finns and to analyze them for ^{90}Sr and calcium (publication No. 15).

In March 1966 the Skolt Lapps contained in the 24-hr urine 6.8 pCi ^{90}Sr and 29 mg Ca, the southern Finns 7.5 pCi and 220 mg, respectively. When calculated per g Ca this gave to the Skolts 97, to the southern Finns 32.5 pCi/g Ca. Thus, the value of Lapps based on calcium unit was 3 times higher although the excreted activity was the same. The same Lapp group contained 4.6 pCi ^{90}Sr/kg blood, the southern Finns 4.4 pCi/kg, respectively. The ratio of ^{90}Sr in the 24-hr urine to that in kg blood was for Lapps 1.5, for southern Finns 1.7. This suggests that the absorption of ^{90}Sr was slightly more efficient in the Skolt Lapps because of their low calcium intake and could lead to somewhat higher body burdens but this was not considered alarming. Their ^{90}Sr content has not been studied since, but if bone samples will become available in forensic medicine cases, they will be analyzed since bone cancer has a very low induction dose level and it is feasible to assume that such levels could be reached if the diet contains little calcium and lots of reindeer bone marrow (which is a delicacy highly valued by Lapps).

The ^{55}Fe intake was elucidated in detail by Timo Jaakkola in his Doctoral Thesis in 1969 (publication No. 20). The whole body burden in 1966 was in male Lapps 92-167 nCi, in female Lapps 101-260 nCi. The specific activity of ^{55}Fe in blood, 67 pCi/mg Fe, was in women twice higher than in men because of their menstruation loss of Fe. Over 98 per cent of ^{55}Fe in the diet of reindeer herding Inari Lapps originated from reindeer meat, liver and blood, but 6-15 per cent of that in the fishing Utsjoki Lapps was derived from salmon and cod caught in the Arctic Ocean. Because of the low beta energy of ^{55}Fe the radiation dose obtained even in the maximal year, 1966, 1.1 to 3.7 mrad for the whole blood, remained low, ca. 0.1 to 0.2 per cent of the maximal permissible body burden recommended by the ICPR. Because of its short physical half-life the ^{55}Fe in all

constituents of the above foodchains decreased very rapidly in the following years.

The total radiation dose to be received by the present generation of Lapps between 1956-85 was estimated in 1969 (publication No. 22). Two nuclides, ^{137}Cs and ^{210}Po, completely dominated the dose to the whole body and genitals. For ^{137}Cs the total dose commitment was estimated to be 1.1 rem, for southern Finns 26 mrem for this period (30 years). The dose commitment from the natural radionuclide ^{210}Po which is also enriched by the foodchain lichen-reindeer-man was estimated by Kauranen and Miettinen (paper No. 25) to be in Lapps' gonads 2.5 rem/30 yrs, in their liver 5 rem/30 yrs. These natural radiation doses are additional to the normal background dose about 3 rem/30 yrs. Thus, the extra dose from ^{137}Cs, 1.1 rem/30 yrs, will be small compared with the natural total dose, 5-8 rem/30 yrs of these Lapps.

In the years 1963 and 1964, when the ^{137}Cs body burdens were rapidly rising and the annual radiation dose of the adult male Lapps from ^{137}Cs alone was approaching 200 mrem/y, much attention was paid to eventual protective measures to reduce the dose from ^{137}Cs. It was concluded, however, that the extra dose would remain too small to warrant any such measures. The situation was sensitive. Any doubt cast on the edibility of reindeer meat could have ruined the market of this meat, which is the Lapps' only income and would have compelled them to eat even more of it themselves in lack of any income! Any compulsary change of their diet also could have been more deleterious to their health than the small, extra radiation dose obtained. Actually, the Lapps' dose from ^{137}Cs never even approached the maximal 500 mrem/y -level recommended by the ICRP[x]. Instead, we decided to continue annual measurements of their body burdens for some years to come and also regularly to check that no unexpected changes would take place in their diet. Their total body dose was also to be studied more carefully, ie. the dose from other nuclides and from external radiation. The body burdens of Finnish Lapps were

[x] except for a few individuals in one or two years.

actually measured annually until 1977. On the basis of the values measured between 1961-77 and estimated between 1956-60 and 1978-85 the total dose from ^{137}Cs between 1956-85 will be to the adult male reindeer breeders ca. 1800 mrem/30 y., to the adult females ca. 1100 mrem/30 y., and to the boarding school children from the Lapp families ca. 450 mrem/30 y. If we approximate two children per family, the average dose for the whole Lapp population, all ages, will be ca. 950 mrem/30 y. This is only slightly less than the 1969 estimate 1.1 rem/30 y.

The forecasts remained quite accurate because reindeer meat was the dominating source of ^{137}Cs and no noticeable change took place in the consumption rate of this food item.

Location of the Lapp families studied for ^{137}Cs body burdens are presented in Fig. 1. The lichen and reindeer samples were also collected from these areas. ^{137}Cs in lichen between 1961 and 1977 is presented in Fig. 2, that in reindeer meat in Fig. 3 and ^{137}Cs in male reindeer herders in Fig. 4.

During 1970-72 ^{210}Po was more closely studied in wild land animals (papers No. 26 and 38), in aqueous animals (papers No. 27, 39 and 47) and the specific activity of ^{210}Pb was determined in some environmental items (papers No. 48 and 56). Environmental gamma radiation dose in Lapland and southern Finland was also measured (paper No. 28). The biological half-time of ^{137}Cs and ^{24}Na in man was determined (paper No. 53). The occurrance of ^{137}Cs in the biosphere, evaluated with environmental and metabolic studies, was elucidated in the Doctoral dissertation of Erkki Häsänen in 1972 (paper No. 57).

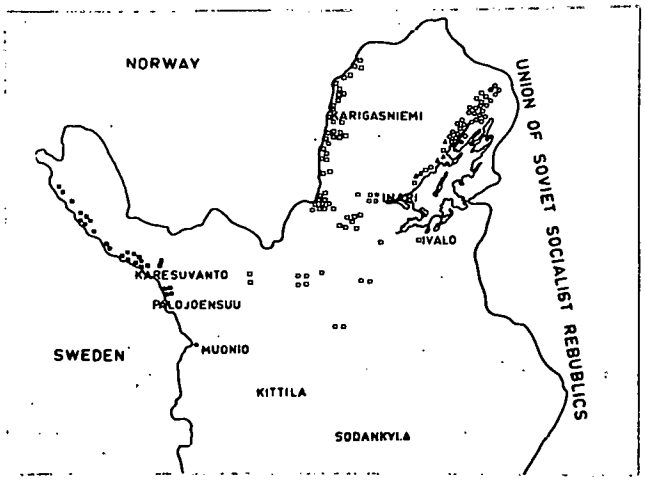

Fig. 1. Geographic distribution of the Lapps studied.
■ Nomadic Mountain Lapps
□ Settled Mountain Lapps
△ Fisher Lapps
○ Skolt Lapps
One dot represents one family.

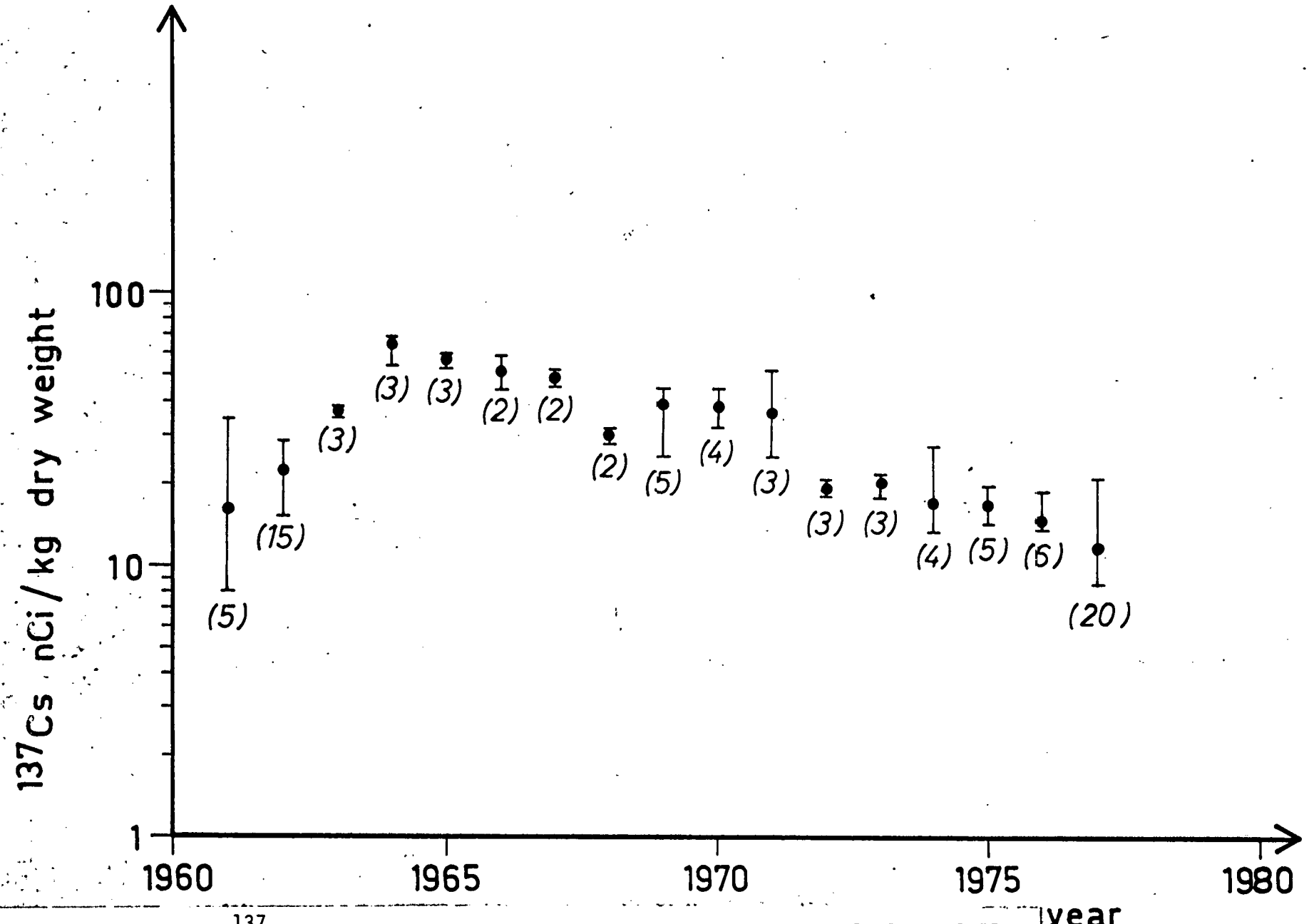

Fig. 2. ^{137}Cs content of Caldonia alpestris collected between 1961 and 1977. The range of values is indicated by vertical bars. (Papers No. 83 and 97).

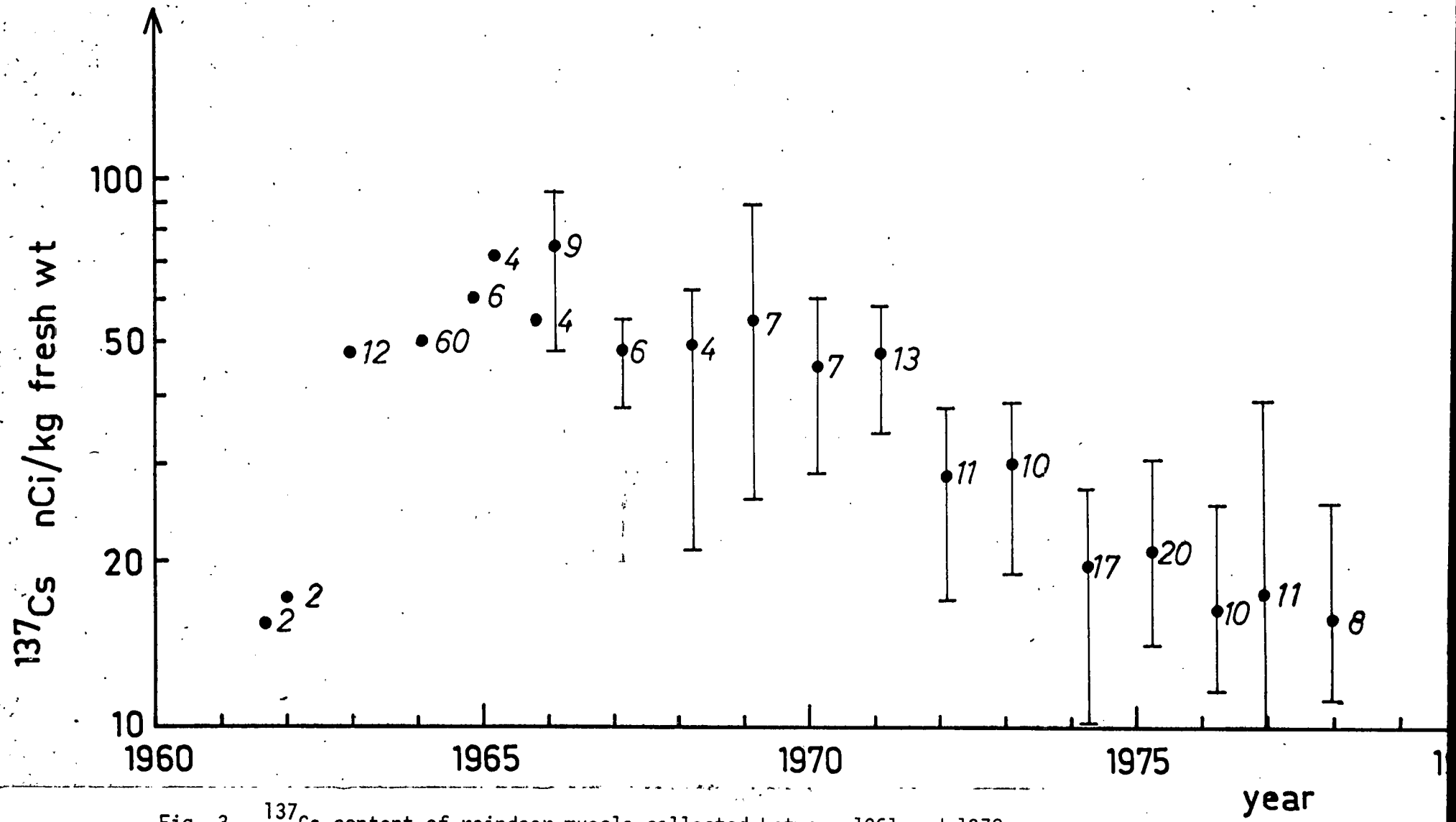

Fig. 3. ^{137}Cs content of reindeer muscle collected between 1961 and 1978. The range of values is indicated by vertical bars and the number of measured samples is shown. (Papers No. 83 and 97).

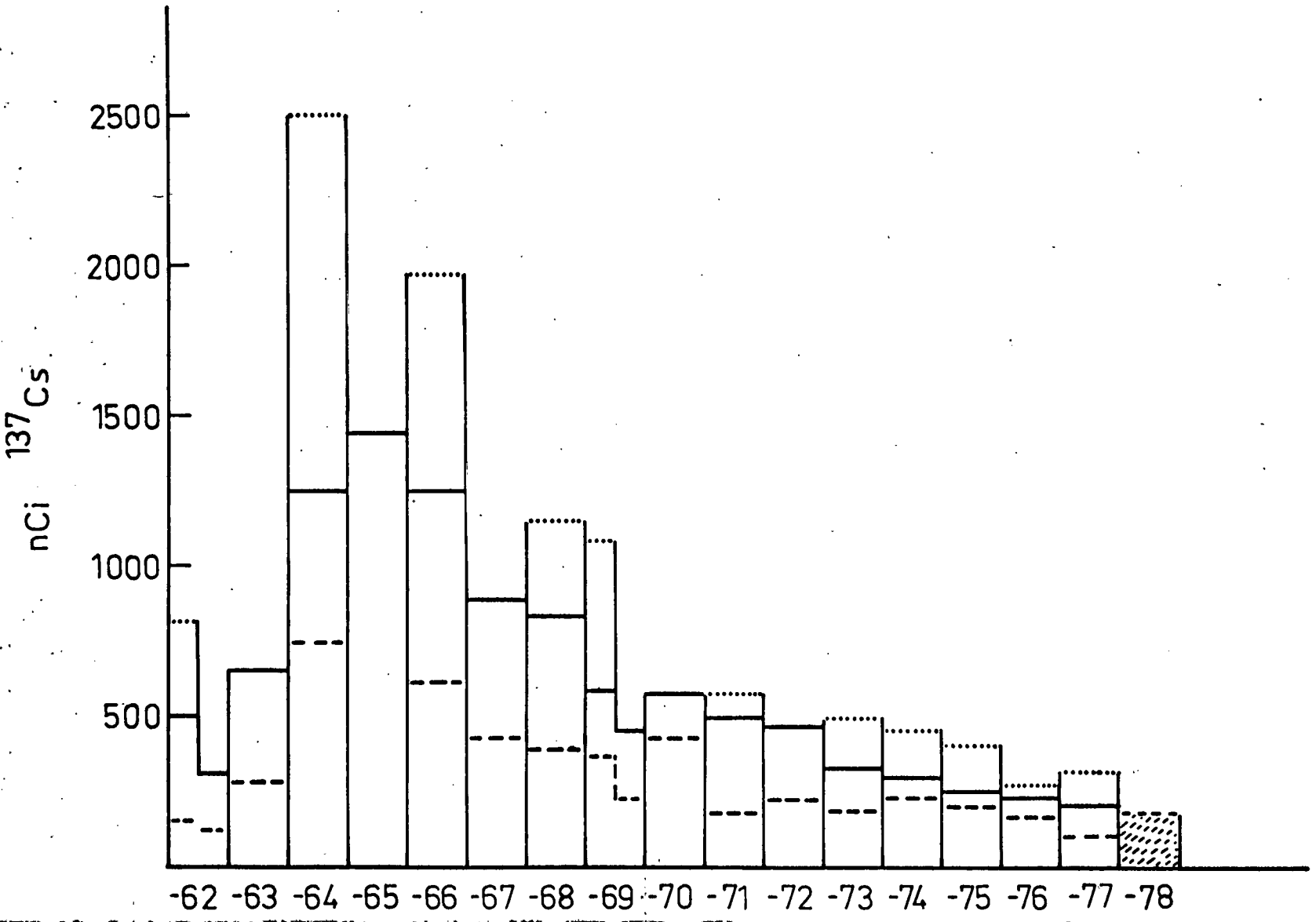

Fig. 4. ^{137}Cs content of male reindeer-herders from the Inari region, 1962-1977.
Mean values ——; values of one man with a high body burden ...;
" " " low " " ---.
(In 1962 and 1969 both spring and autumn values are marked).
The figure is from paper No. 97. The 1978 value is only an estimate.

2. Studies of transuranium nuclides between 1973-1976

Studies on transfer of transuranium nuclides along the foodchain lichen-reindeer-man were started in 1973. During the three next years, 1974-76, much work had to be devoted to methodological studies and to increasing the spectrometric facilities. Finally, 8 separate semiconductor detectors with vacuum chambers and multichannel alpha-spectrometers were obtained. The low activity of the environmental samples and the long counting times involved - up to 7 days per sample - required this large counting capacity. The method for isolation of $^{239,240}Pu$ and ^{238}Pu from lichen for alpha-counting was based on that developed in the HASL (HASL-300, E-Pu-06-01). For determination of this nuclide from reindeer meat a slightly different procedure published by K.M. Wong (Anal. Chim.Acta 56 (1971) 355) was used but modified by adding an iron extraction step with di-isopropylether because liver contains much of iron. Results on $^{239,240}Pu$ and ^{238}Pu contents in about 20 lichen samples between 1960-73 (paper No. 62) and ca. 20 reindeer liver samples between 1964-1973 (paper No. 63) was reported in 1973 already. Both studies were continued and more extensive results reported in the 3rd European IRPA Congress in May 1975 (paper No. 68). This report gave a good overview of $^{239,240}Pu$ in lichen from 1960 to 1974 (Fig. 5). A high peak, 230 pCi/kg was measured in 1963-64. The 1974 level was only about 1/10th of that a decade earlier indicating a "biological half-time" of 2 to 3 years for plutonium in lichen.

Reindeer tissues contained in 1967 on an average 10.8 (liver), 0.13 (meat) and 0.02 (blood) pCi $^{239,240}Pu$/kg fresh weight. Based on these figures and a known intake of liver, meat and blood by the Lapps their daily intake was estimated: 0.111 pCi by men, 0.043 pCi by women. It was also shown that the ratio $^{238}Pu/^{239,240}Pu$ in lichen increased from 0.03 to 0.08 from 1960 to 1974, evidently because of the fallout of ^{238}Pu from the SNAP-9A satellite power source.

Lichens on field were labelled in 1975 (paper No. 71) by spraying a mist of a ^{236}Pu solution on them. About 70 % of the isotope in the spray was thus fixed in the lichen. Its elimination rate and transfer from top into lower part was studied in the following years.

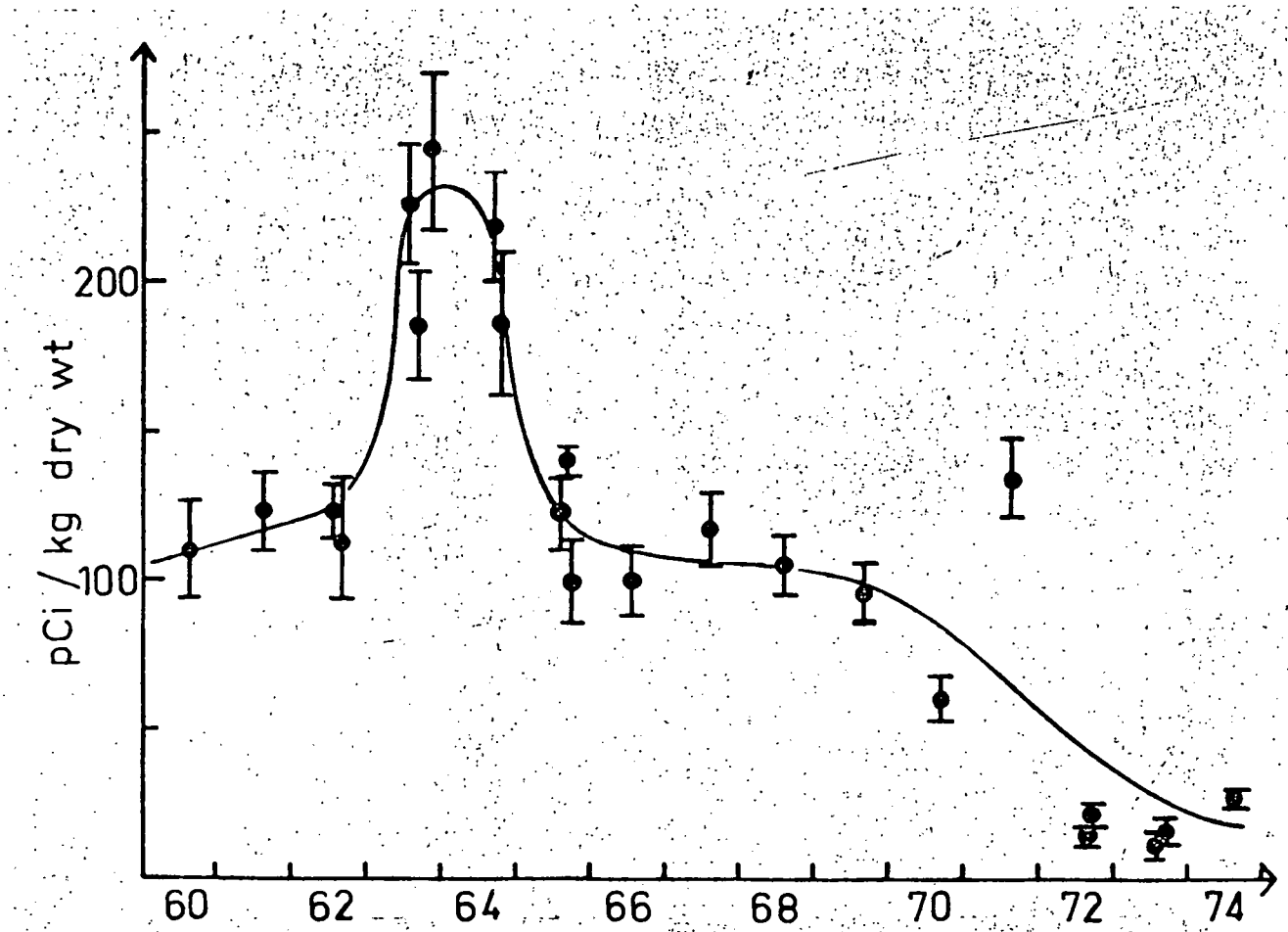

Fig. 5. $^{239}Pu+^{240}Pu$-content in lichen in Finland during 1960-1974. Standard deviation of the radioassay (±2δ) is indicated.

As "fringe benefits" of this project student work on plutonium in aquatic foodchains and plutonium uptake by a sea plant (Enteromorpha) was carried out in 1975 (papers No. 70 and 72). The results obtained on plutonium were summarized in the triannual report of 1976. Results from a large number of analyses was now available.

M. Hakanen and T. Jaakkola (paper No. 77) reported distribution of $^{239,240}Pu$ and ^{238}Pu in numerous tissues of reindeer. In fact, several whole animals were bought, dissected and analyzed to have a total body content and organ-distribution figure for the whole animal. Reindeer is the only large animal which gets an important part of its total plutonium from its normal diet - all other animals including the closely related moose have obtained almost all of their plutonium via inhalation. Particularly interesting results gave a comparison of plutonium in reindeer and elk tissues in different years, those of high (1964-66) and low (1975-76) fallout (papers No. 78, 86), of which the latter paper is already from the year 1977. As can be seen, in the years of high atmospheric plutonium (Fig. 6) the lungs of reindeer and elk had the same average concentration (from inhalation), ca. 0.5 pCi/kg fr.wt., but the liver of reindeer contained 20 times more plutonium (10 pCi/kg) than the liver of elk (0.5 pCi/kg).

With low atmospheric plutonium content (Fig. 7), again, the lungs of both animals contained about the same, 0.05 pCi/kg, but now the liver of reindeer contained 100 times more than that of elk. It seems that the liver content indicates particularly the dietary intake of plutonium.

The ^{236}Pu retention study in lichen which was started in 1974 (paper No. 71) was continued (paper No. 80). It was estimated that the biological half-time of ^{236}Pu in lichen was short, 1 to 1.5 years, which corresponds to a mean residence time of about 2 years. This is in agreement with results obtained from analysis of fallout plutonium in lichen. By student work plutonium in Baltic sediments was determined (paper No. 81). The first results on plutonium in human tissues (two subjects were reported (paper No. 79).

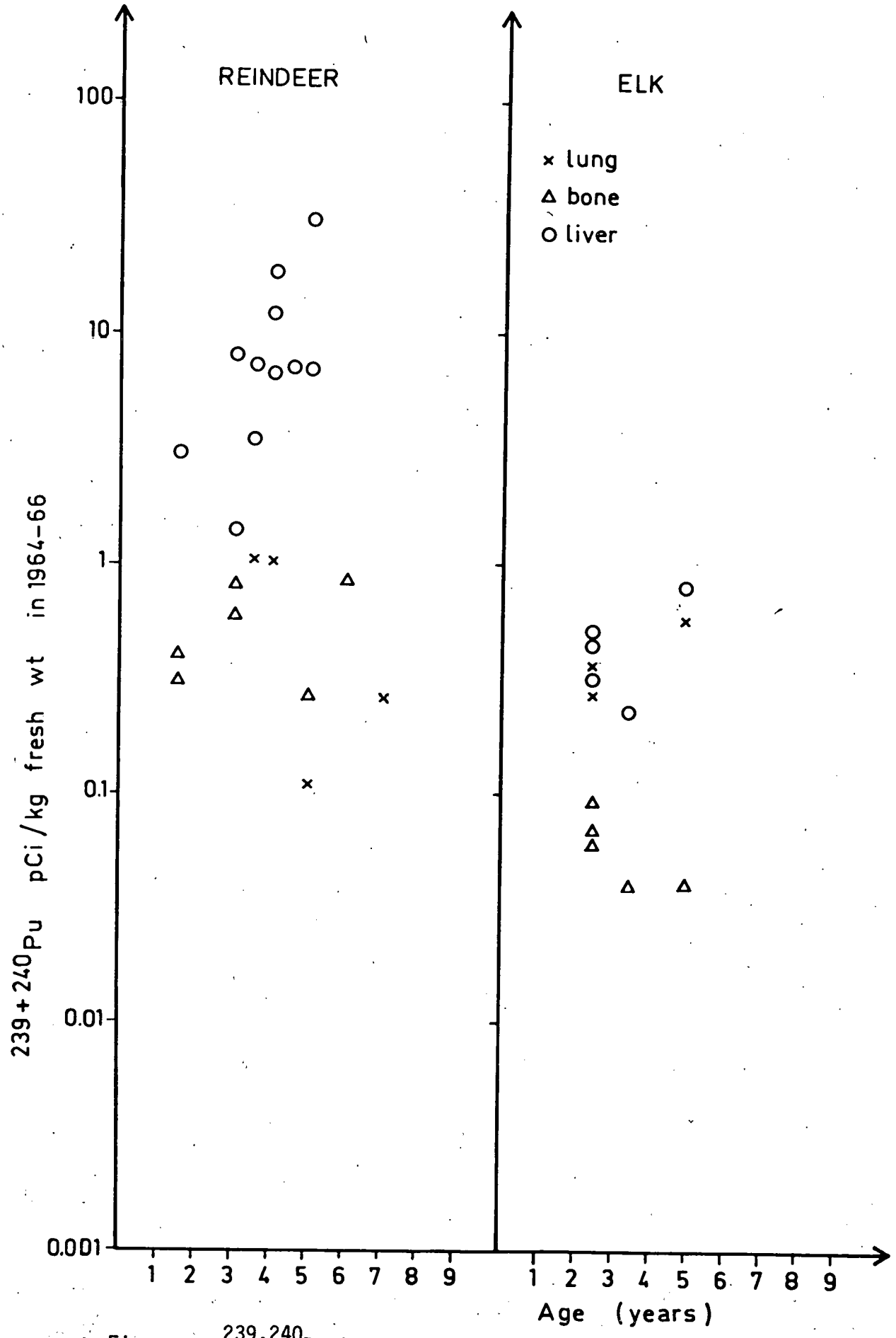

Figure 6. $^{239,240}Pu$ in reindeer and elk liver, lung and bones in 1964-66.

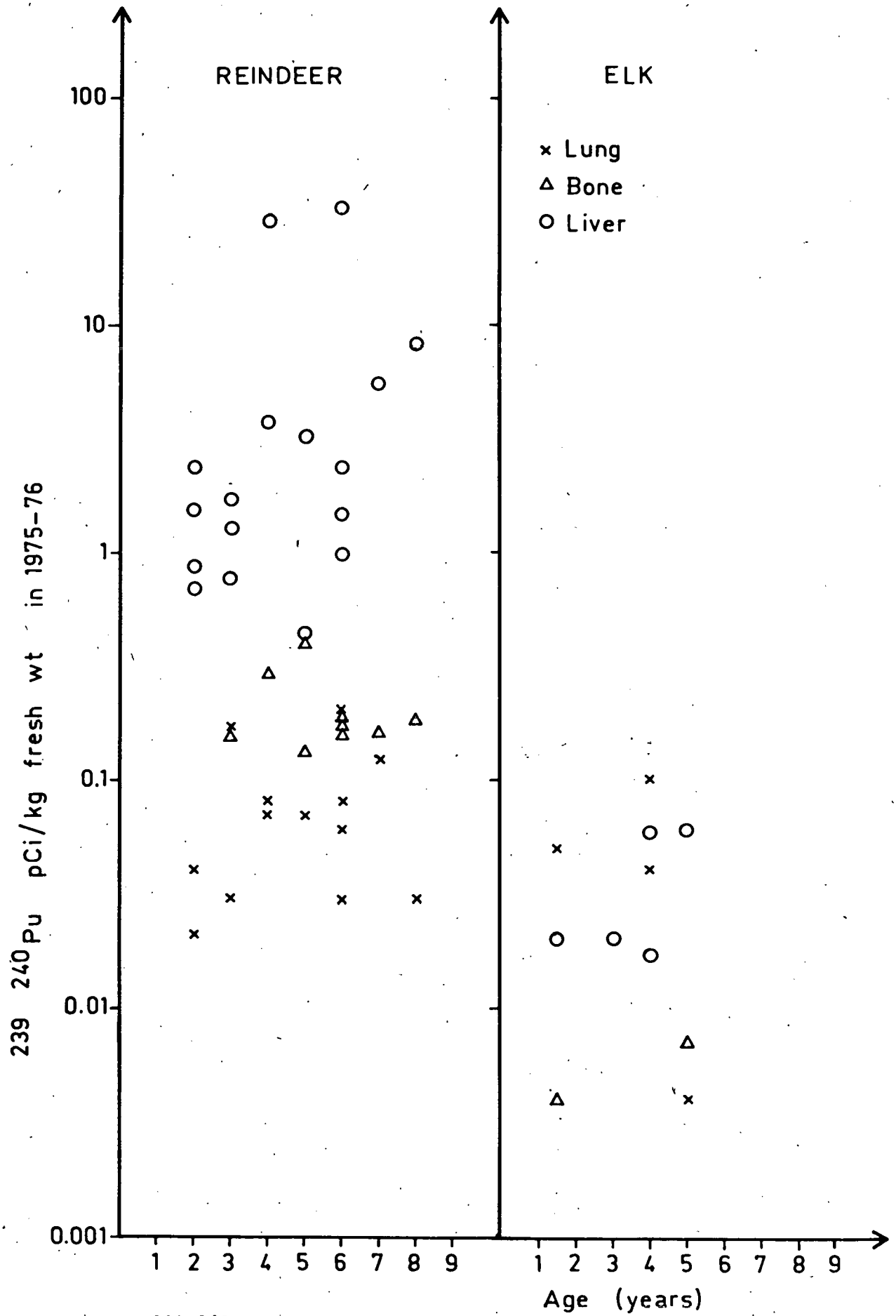

Figure 7. $^{239,240}Pu$ in reindeer and elk liver, lung and bones in 1975-76.

3. Studies on Transuranium nuclides during Aug. 1976 - Nov. 1978

Annual reports exist for the two first years of the last triannual period. The results previously reported are briefly summarized below. The newest results obtained during the last year will be described in greater detail in the next chapter.

A large number of plutonium-analyses from four tissues of reindeer, lung, kidney, liver and bone, exists now (paper No. 86 and 93). They cover the years 1963-77. Both the age of the animal when slaughtered and the years which it lived effect its plutonium content. Maximal concentrations of $^{239,240}Pu$ in the liver of 2 to 4 year-old reindeer, 10-20 pCi/kg fr.wt., were measured in 1967, five years after the cessation of the bomb tests and 3 to 4 years after maximum in lichen. The animals had grazed their whole life highly active lichen. When the total body plutonium (estimated on the basis of liver analysis) was divided by the estimated dietary intake during the animal's total life span the ratio $4.4 \pm 0.5 \times 10^{-5}$ was obtained. As an annual lichen consumption the value 600 kg dry lichen was used. This value is possibly overestimated. If the lichen consumption has been smaller, the value for the ratio increases even more. The above value already is higher than that reported by the ICRP for man ($3 \cdot 10^{-5}$ to 10^{-6}). The latter value is based on laboratory experiments with small animals. Absorbability from lichen, in which the plutonium is probably as a protein complex, may be higher than in laboratory experiments. There exist some observations from the Utsjoki region that reindeer feeds in winter only about 0.7-1 kg dry lichen/day. With this intake value the absorbability becomes $1.3 \cdot 10^{-4}$ which is already a 1 to 2 orders of magnitude higher value than the ICRP figure. It is difficult to confirm such an estimate because it is almost impossible to measure the amount of lichen the wild animals feed per day, but the above estimates do suggest that the absorbability of organically bound plutonium may be considerably higher than the ICRP figure suggests.

Studies on the distribution of plutonium in four whole reindeer were continued (first results were reported in paper No. 77). More results

were reported in paper No. 87. Plutonium concentrations in different bones of the same animal showed consistently considerable differences: if the concentration in the total skeleton was marked by one, teeth contained 2 to 4 times, sternum, vertebrae and humerus 1.5 - 1.7 times, tibia, femur and ribs were close to 1, but skull 0.5, ulna 0.4 and antlers 0.3. The relative plutonium concentrations in reindeer are very similar to those in beagle dogs. Particularly interesting is the relatively high plutonium concentration in teeth.

In paper No. 88 preliminary results on ^{241}Am in reindeer liver, lung and bone were reported. High values were found in bone in comparison to those in lung and liver.

The field experiment started in 1974 by labelling growing lichen with a ^{236}Pu spray was continued by analyzing more samples (paper No. 90). Results from three years' time proved exponential elimination with a biological half-time of about 500 days. Another plot of lichens was labelled by ^{241}Am.

Emphasis in 1976 was in human tissue analyses and a large number of results became ready (paper No. 89). Plutonium concentrations in lung, liver and bone of 23 southern Finns was reported. In human liver a maximum, ca. 1 pCi $^{239,240}Pu$ per total liver, is observable at the age of about 30 to 40 years. People who died in this age in 1977 were 22 ± 5 years old in the year of the maximal fallout, 1963, and this maximum may reflect the high physical activity people of 22 years usually have. From northern Finland bone values of five none-Lapps from 1964 and a pooled placenta sample of 10 Lapps from 1966 were measured. The results did not differ from those from southern Finland.

Plutonium concentration in the bones (ribs) of southern Finns was only about 12 per cent of that in their liver (on wet weight basis). This was puzzling because from other countries, eg. the USA and Japan, higher concentrations in bone (vertebrae) than liver were reported. Although vertebrae usually contains 1.5 times more than ribs, this does not explain the discrepancy.

Last year (1978) the focus was completely in human samples. Samples from 27 new subjects were obtained so that the number of subjects analyzed regarding liver grew to 50; about half of them were also analyzed regarding lung and bone (paper No. 91). Better statistics for all age groups were now observed with greater number of cases. Results on liver were interesting. There was a clear increase in plutonium concentration observable up to 40 years of age but no change thereafter. Calculation of the plutonium intake via inhalation showed that there has been an almost linear increase up to 35-40 years of age but in higher ages none. More than 35 years ago (1942) there was no plutonium in the atmosphere. About 4.5 per cent of the plutonium inhaled (or 17 % of that deposited in lungs) during the life-time is retained in the liver.

Our value in liver, 0.31 pCi/kg wet wt., is about half of that in Mexico and the USA. Fallout in Finland (eg. ^{137}Cs, ^{90}Sr) is also about half of that in New York. The same discrepancy regarding bone values between Finland and the USA discussed above was again observed. Our values are relatively much - 5 to 10 times - lower. Because of a small number of cases, different ages of the persons, and different years of their death a meaningful international comparison is still almost impossible.

Analyses of ^{241}Am in reindeer, began last year (paper No. 88), were continued (paper No. 94). Since reindeer bone contains over 100 times more radioactivity of ^{228}Ra and its daughters ^{228}Th and ^{224}Ra than of ^{241}Am and the alpha energies overlap extreme purification of the ^{241}Am preparate is necessary. A method was developed to remove the disturbing radium and thorium nuclides from the solution. Analyses gave about the same ^{241}Am concentration in reindeer bone as of $^{239,240}Pu$: 0.3 pCi/kg fr.wt. Since the ratio of the above nuclides, $^{241}Am/^{239}Pu$, in lichen is 0.25, ^{241}Am is enriched in reindeer bones from the diet four times more efficiently than plutonium. This is important, because the same is probably true regarding man and the ^{241}Am content in the environment will grow (being daughter of ^{241}Pu) during the next half-century.

A new method was developed for the beta-emitting ^{241}Pu, the mother of ^{241}Am. The method is based on chemical separation and measurement by liquid scintillation spectrometry. Lichen and beard-moss from the years 1962-69 contained 2000-6000 pCi ^{241}Pu/kg dry weight and reindeer liver 28-45 pCi/kg wet wt.

Paper No. 96 reports concentrations of four plutonium nuclides and ^{241}Am in lichen since 1960 (Fig. 8). The present concentrations are less than 10 per cent of those in the year of maximal concentrations, 1963. Only a few per cent of the plutonium in lichen "carpet" is presently found in the living part of lichen.

4. Studies of transuranium nuclides during the final year, Nov. 15, 1978 - Aug. 14, 1979

During the 9 months of the final year five papers have been completed (Nos. 98-102), of which 2 are expanded versions of earlier papers (Nos. 101 and 102), the other three new ones.

In paper No. 99 plutonium in Helsinki air is reported. This is important to know in order that the amount obtained via inhalation could be estimated for construction of a metabolic model for plutonium in southern Finns. In 1963 maximal concentrations*, 523 aCi/m^3 of $^{239,240}Pu$ were measured. In 1970 the value was 26, in 1977 11. For comparison, ^{137}Cs was also measured from the same airfilter. Throughout these years there was about 1 % $^{239,240}Pu$ activity from ^{137}Cs activity. The Helsinki concentrations are about 1/2 to 2/3 of those in Munich, New York or Chilton (U.K.).

To have a better picture on the $^{241}Am/^{239,240}Pu$ ratio in the environment these nuclides were studied in cumulative fallout in the form of bottom sediments of a lake and of the Gulf of Finland (paper No. 100). Considerable method-development was necessary to get pure ^{241}Am preparations from the sediment samples. The above ratios were 0.25 and 0.20 for the

* aCi = attocurie = 10^{-18} Ci = 37 nBq

marine and lake sediments. These ratios are about the same as earlier determined in reindeer lichen.

Paper No. 102 which describes a new method for determining ^{241}Pu isolated from environmental samples by liquid scintillation counting is a finalized version of the earlier paper No. 95.

In previous years almost the only kind of human bone analysed was rib. Now, several different bone types have been analysed for plutonium. The results are reported in paper No. 98.

As was earlier observed, our bone values in relation to other tissues are considerably lower than in other countries.

The new results are also somewhat astonishing in-so-far that no great difference between the different bone types is noticeable. According to litterature, rib values are usually close to the average of the total skeleton; this is also fairly well corroborated by some animal results (beagle, reindeer, pig). In this work the average vertebrae-to-ribs ratio is 1.4 and vertebrae-to-femur ratio 1.5. These are small differences. Femur shaft and ribs showed very similar plutonium contents in this study which is also an unexpected result.

Another important result obtained was the observation that the distribution of plutonium between different tissues of man is fairly constant the concentration level depending only on the intake and/or rate of metabolism. This makes possible meaningful use of mathematical models.

This report contains all results of this project up to this date. Several of the papers presented in the Annual Reports have been preliminary. They will be later presented in final form in several Dissertations and articles to be published in scientific journals.

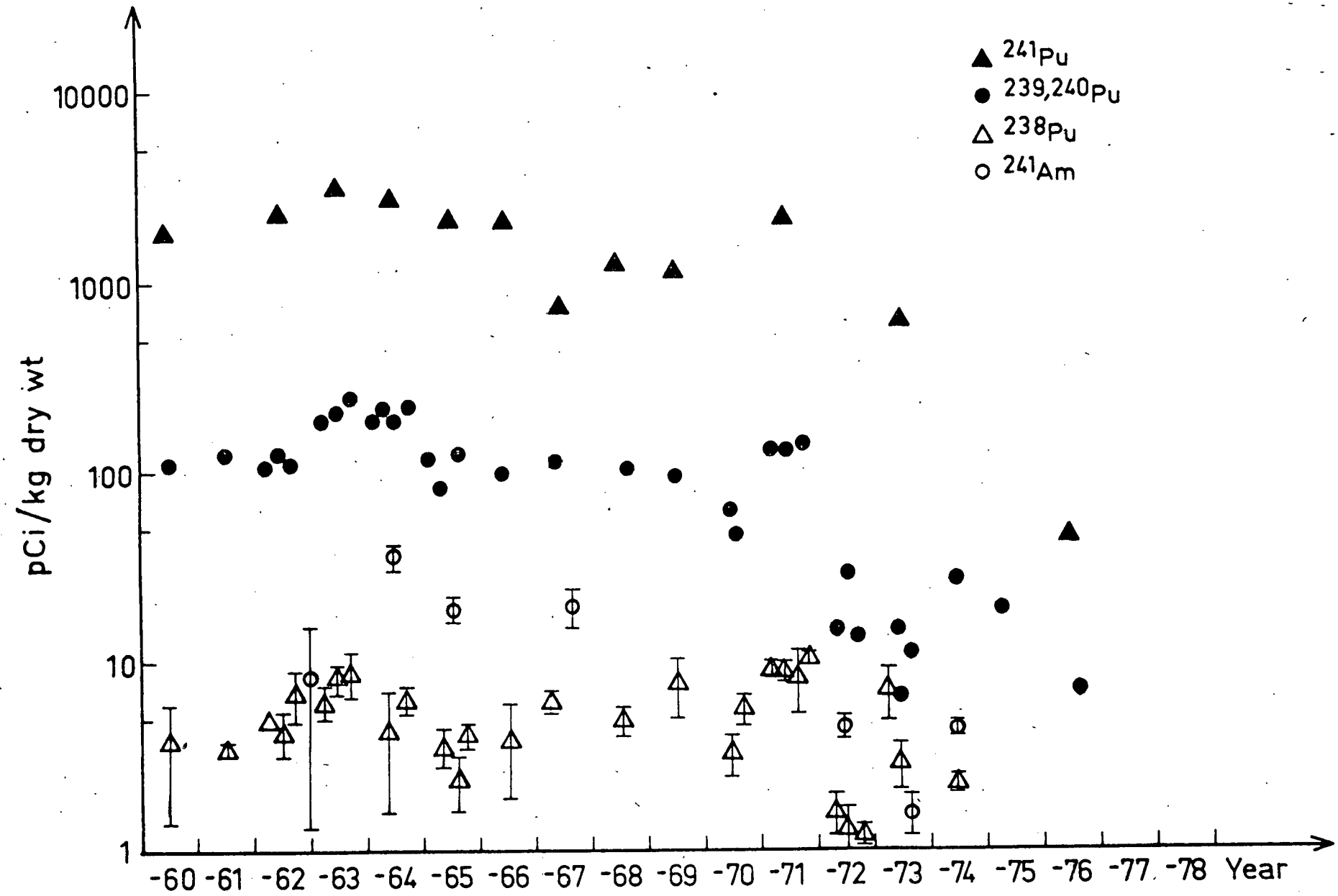

Fig. 8. The concentrations $^{239,240}Pu$, ^{238}Pu, ^{241}Pu and ^{241}Am in lichen (Cladonia alpestris) in Finland during 1960-1976. The standard deviation of the radioassay (1σ) is indicated in the connection of the ^{238}Pu and ^{241}Am results.

Summary and conclusions

It is difficult to summarize in concised form the results of 14 years' work and 102 scientific papers except in general terms. In a period of increasing body burdens this project elucidated in great detail the radioactivity of the diet and tissues of reindeer and of reindeer herding Lapps, who consume large amounts of reindeer muscle and other tissues. The detailed and precise results made possible accurate forecasts of the change of radioactivity on all trophic levels and in the critical items of the foodchains elucidated.

The accurate and reliable forecasts were made possible by a detailed knowledge of all environmental and dietary factors involved. The reliable forcasts made possible correct early decisions regarding eventual application of protective measures for reduction of the extra dose from ^{137}Cs to the population group submitted to the highest extra dose, the adult male reindeer herders.

The decision made was: no protective measures were necessary or recommendable, although a few individuals' dose commitment from ^{137}Cs in the body exceeded 350 mrem/y in 1965. Any "protective" measure which would have cast some doubt on the safety of reindeer meat as human food from radiation point of view could have jeopardized its markets. Since the Lapps' only income was reindeer meat their loss of income would have caused them much greater health hazards than the temporary extra radiation dose which would only grow to 1 rem/30 years.

This project also elucidated the relatively high natural radiation dose Lapps have always received from ^{210}Po (eg. in genitals 2500 mrem/30 y). This nuclide is cumulated in lichen from natural fallout and becomes just like ^{137}Cs enriched into reindeer (particularly its liver) and Lapps. ^{210}Po approximately doubles the natural background dose of Lapps in comparison to non-reindeer consumers.

The transuranium studies carried out regarding the foodchain lichen - reindeer - reindeer herders (and for comparison in southern Finns) have given a lot of information on the four plutonium isotopes (238, 239+240, 241) and ^{241}Am in the environment and in man.

Since the Lapps get (from reindeer tissues, particularly liver) about ten times more $^{239,240}Pu$ in their diet than other populations, analyses of their tissues post mortem could show wheather the absorbability of protein-bound plutonium is really of the order of $3 \cdot 10^{-5}$ as proposed by the ICRP or higher as suggested by our reindeer studies.

Unfortunately the number of autopsy samples obtained from this small population (ca. 3500 Lapps in Finland altogether) is very small - just a few cases annually at best. The results obtained so far are too few to warrant any conclusions. But it would be extremely important to be able to continue this study for a few years until a sufficient number of autopsy samples have been analysed to give a statistically reliable answer.

Recommendation 1.

Also transuranium results from the southern Finns are scientifically quite valuable, because the analytical results from all countries are still so few that international comparisons of tissue levels are almost impossible. There ought to be some 30 to 50 autopsy samples from the same tissue of subjects of the same population, about the same age group, died about the same year, and these should be analyzed by a well standardized, reliable and cross-checked method in each country before a reliable international comparison would become possible.

Recommendation 2.

An interesting observation made in this study is also the extremely low plutonium content in the liver of persons who suffer from a fatty degeneration of liver (in most cases probably caused by alcoholism). Such a pathological liver is evidently devoid of the plutonium-binding protein. This observation ought to be confirmed.

Recommendation 3.

An interesting observation is also that there is a high tendency of ^{241}Am to become enriched into reindeer bone. Since the amount of this highly

toxic nuclide ($T_{1/2}$ 433 y, which is the daughter of ^{241}Pu ($T_{1/2}$ 14.9 y), will increase in the environment during the next half a century, and since it may be equally effectively enriched into human bones, too, its (^{241}Am) occurrance and enrichment should be studied in detail. Nothing is known so far about its occurrence in human bodies. Research of ^{241}Am in environmental samples particularly in human tissues, is methodologically extremely demanding. Only a few laboratories in the world have the necessary experience and availability of materials and they should be given the necessary resources.

Recommendation 4.

Recommendation 5. Finally, the occurrence of $^{239,240}Pu$ and ^{241}Am in all important food items and in the average diets of various population groups should be studied. Too little information exists still of the dietary pathways of these toxic transuranium elements into the human body.

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