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THE TRANSFER FACTOR OF DAIRY MILK FROM FALLOUT OF NUCLEAR EXPLOSIONS TO THE ACTIVITY CONCENTRATION IN MILK WITH RESPECT TO ^{137}Cs AND ^{90}Sr

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Introduction

The radioactivity produced by the explosions of nuclear devices has been transported to Sweden via the stratosphere. An exchange of air takes place between the stratosphere and the troposphere, from where the activity mainly reaches the ground by means of washout by the precipitation. The activity which reaches the ground is taken up partly directly by the foilage of the plants and partly by the roots. The activity reaches the root zone by percolation of rainwater, by diffusion and through mechanical cultivation in agriculture.

Transfer model according to UNSCEAR

In the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) a theoretical model has been used to estimate the activity in milk as a function of fallout (1). The model is as follows:

$$C(i) = B_1 f(i) + B_2 f(i-1) + B_3 \sum_{m=1}^{\infty} e^{-B_4} \cdot {}_m f(i-m)$$

where $C(i)$ is the activity concentration in milk during the year i

$f(i)$ is the fallout density this year

$C(i)$ and $f(i)$ are computed for a calender year.

The constant B_1 reflects the direct uptake of year i and B_2 the contribution of the preceding year. In the last term a summation is made over the fallout of all the preceding years. The fallout

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terms are weighted with an exponential term where the constant B_4 describes the decay of the nuclide and its increasing unavailability to the plants in the root zone. Finally the whole summation is weighted with the constant B_3.

The activity concentration C(i) also depends on the feeding circumstances of the cows i.e. the distribution between fresh fodder, hay, concentrated feed, additional mineral feed and the time of outdoor grazing. The constants B_{1-4} have been computed by regression analysis with the method of least squares.

The transfer factor P_{23}, which describes the overall transfer from fallout on the ground to activity in milk, is defined as $\frac{\int_{-\infty}^{\infty} C(t)dt}{\int_{-\infty}^{\infty} f(t)dt}$

mean values for whole years are used

is found that $P_{23} = \frac{\sum_{-\infty}^{\infty} C(i)}{\sum_{-\infty}^{\infty} f(i)}$, or $P_{23} = \frac{B_3}{B_4} + B_1 + B_2$.

where C(i) is the mean activity in milk for the year i and f(i) is the mean fallout of the year i.

Assumptions of the analysis

Regular measurements of ^{137}Cs in milk from Swedish dairies have been made since 1962 and of ^{90}Sr since 1966 (3,5). Fallout measurements of ^{137}Cs are available since 1962 (2).

The fallout of strontium has been estimated by dividing the cesium-activity with 1.6 (UNSCEAR). Data of the fallout of ^{90}Sr on the northern hemisphere were used to estimate the fallout before 1962 (1). This has been done to improve the estimations for the years 1962 and 63 for ^{137}Cs.

The countrywide means of the activity in milk exist from 1962 for cesium and from 1966 for strontium.

These mean values are weighted for the consumption. To find the corresponding countrywide means for the fallout is more difficult. An approximation has been made by computing the mean value of the fallout at the measurement stations in Tumba, Gothenburg and Ljungbyhed for the period after 1962.

Due to the approximations used the error analysis is difficult.

Results

^{137}Cs

In Table 1 the values for B_{1-4}, P_{23} and X^2 are given, where $X^2 = \Sigma\ (X \text{ measured } (i) - X \text{ computed } (i))^2$. The values from Denmark and Norway are given for comparison (1).

Table 1. Parameters found by regression analysis of ^{137}Cs in dairy milk

		Country wide mean value	Malmö	Stockholm	Gothenburg	Denmark	Norway
B_1	[Bq year/gK per kBq/ m^2] x)	3.7	2.4	2.8	4.9	2.37	3.52
B_2		2.0	1.3	1.8	0.89	0.69	2.26
B_3		0.62	0.23	0.14	0.86	0.06	2.63
B_4	$(year)^{-1}$	0.26	0.31	0.10	0.31	0.30	0.24
X^2		3.0	19,7	8.8	96	-	-
P_{23}	[Bq year/gK per kBq/ m^2]	8.1	4.4	5.9	8.7	3.23	15.48

In Figures 1, 2, 3 and 4 the computed values of the regression analysis are compared with the measured values.

^{90}Sr

It has been mentioned earlier that the countrywide means are available only since 1966. In Table 2 the countrywide means of B_{1-4}, X^2 and P_{23} are given and for comparison the values from Denmark and Norway. The countrywide means give a satisfactory fit to the model whereas the values for Malmö gives a negative parameter value for B_4.

x) The unit of activity according to the SI-system is becquerel (Bq), where 1 Bq = 27 pCi

Table 2. Parameters of the country wide means found by regression analysis of ^{90}Sr in dairy milk

		Country wide mean value	Denmark	Norway
B_1	[Bq year/gCa per kBq/ m^2]	1.1	0.98	0.70
B_2		1.97	0.46	0.44
B_3		0.18	0.23	1.02
B_4	$(year)^{-1}$	0.09	0.13	0.33
X^2		0.2	-	-
P_{23}	[Bq year/gCa per kBq/ m^2]	5.1	3.12	3.74

Figure 5 shows the estimated and the measured values of ^{90}Sr.

Discussion

The fit to the model of UNSCEAR for the Swedish values for cesium has been surprisingly good, taking X^2 as criterion. The rather high values of X^2 for Malmö, Stockholm and Gothenburg for ^{137}Cs may be due to the fact that the fallout is measured at one geographical point, but the milk sample is a mean value of all milk from a large area.

The Swedish means for the parameters for cesium lies between those for Denmark and Norway. The direct uptake is more in accordance with the Norwegian value. The values from Malmö can be compared to the values from Denmark.

The regression analysis leads to values between the estimated values for Denmark and Norway. It can thus be assumed that the estimation is fairly good despite all the previously mentioned assumptions involved in the analysis.

For further comparison with other countries reference should be made to the UNSCEAR report of 1977.

A report was issued by the Institute in 1972 (4) giving the activity of ^{137}Cs in milk as a function of fallout quantity and time. The function used was:

$$C(i) = a \sum_{t=0}^{3} f(i-t) e^{-\frac{0.693}{T_A} \cdot t} + b \sum_{t=0}^{\infty} f(i-t) e^{-\frac{0.693}{T_B} \cdot t}$$

where C(i) and f(i) has the same meaning as earlier.

a and b are constants

T_A and T_B are decay constants

The year i is taken from 1 May to 31 April next year. For Stockholm and Gothenburg the parameter were computed to:

	a [Bq/l/kBq/m^2]	b	T_A [year]	T_B
Stockholm	6.60	0.13	0.6	30
Gothenburg	9.05	0.18	0.6	30

By dividing a and b by 1.5 gK/l we get a quantity which can be compared with the constant B_1 in the UNSCEAR model. For Stockholm the quantity becomes 4.5 Bq/gK/kBq/m^2 and for Gothenburg 6.2 Bq/gK/kBq/m^2. As can be seen, these values are slightly higher than the constant B_1 given by the UNSCEAR model, where the equivalents were 2.8 and 4.9 Bq/gK/kBq/m^2.

The transfer factors P_{23} for Stockholm and Gothenburg were 4.9 and 7.2 Bq/gK/kBq/m^2, the equivalent factors according to our estimation of the UNSCEAR model were 5.9 and 8.7 Bq/gK/kBq/m^2. Thus it can be concluded that the estimation made in 1972 by the Institute is in fair agreement with the UNSCEAR model.

Summary

In the 1977 UNSCEAR report a model has been used to describe the transfer of fallout from nuclear explosions to the activity in milk.

Swedish data on milk was fitted to this model by regression analysis.

Our data consist of regular countrywide measurements since 1962 for ^{137}Cs and 1966 for ^{90}Sr in milk. Fallout measurements of ^{137}Cs have been made since 1962. To get a better fit, the fallout data has been supplemented with fallout data of ^{90}Sr derived from data of fallout on the northern hemisphere for the years 1957 - 61.

The transfer factors which describe the transfer from fallout to activity in milk were found to be for the countrywide mean values of ^{137}Cs 8.1 Bqyear/gK/kBq/m^2 and of ^{90}Sr 5.1 Bqyear/gCa/kBq/m^2. The transfer factors for ^{137}Cs for Stockholm, Malmö and Gothenburg were 5.9, 4.4 and 8.7 Bqyear/gK/kBq/m^2. These values agree closely to the values found in a survey made by the Institute in 1972. They also seem to agree with the values from Denmark and Norway in the 1977 UNSCEAR report.

References

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Fig. Comparison between the computed values of [illegible] activity in milk and the measured values. The values are country wide means.

o= the computed activity in milk
x= the measured activity in milk

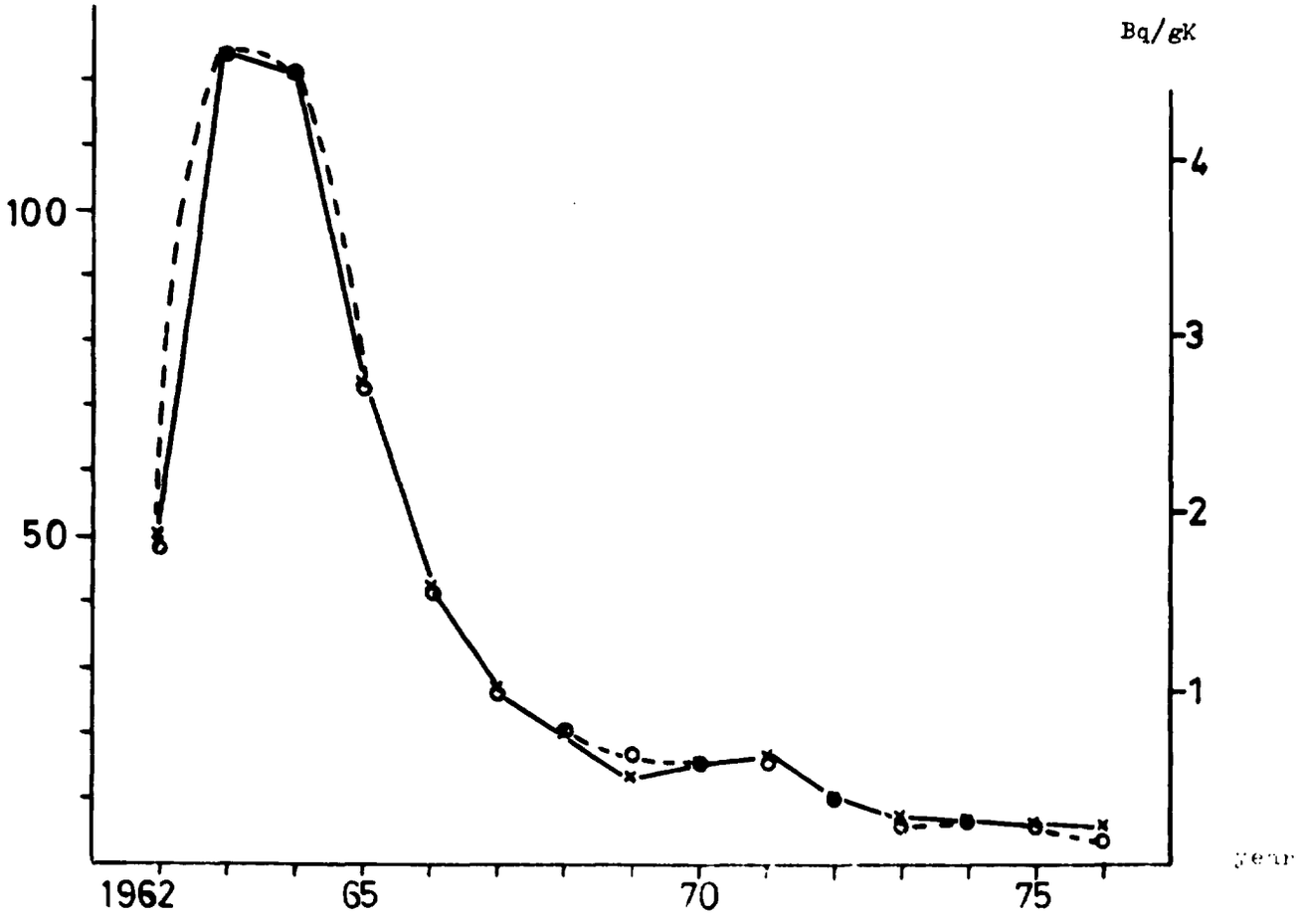


Fig.2 Comparison between the computed values of ^{137}Cs activity in milk from Malmö and the measured values.

x= the measured activity in milk
o= the computed activity in milk

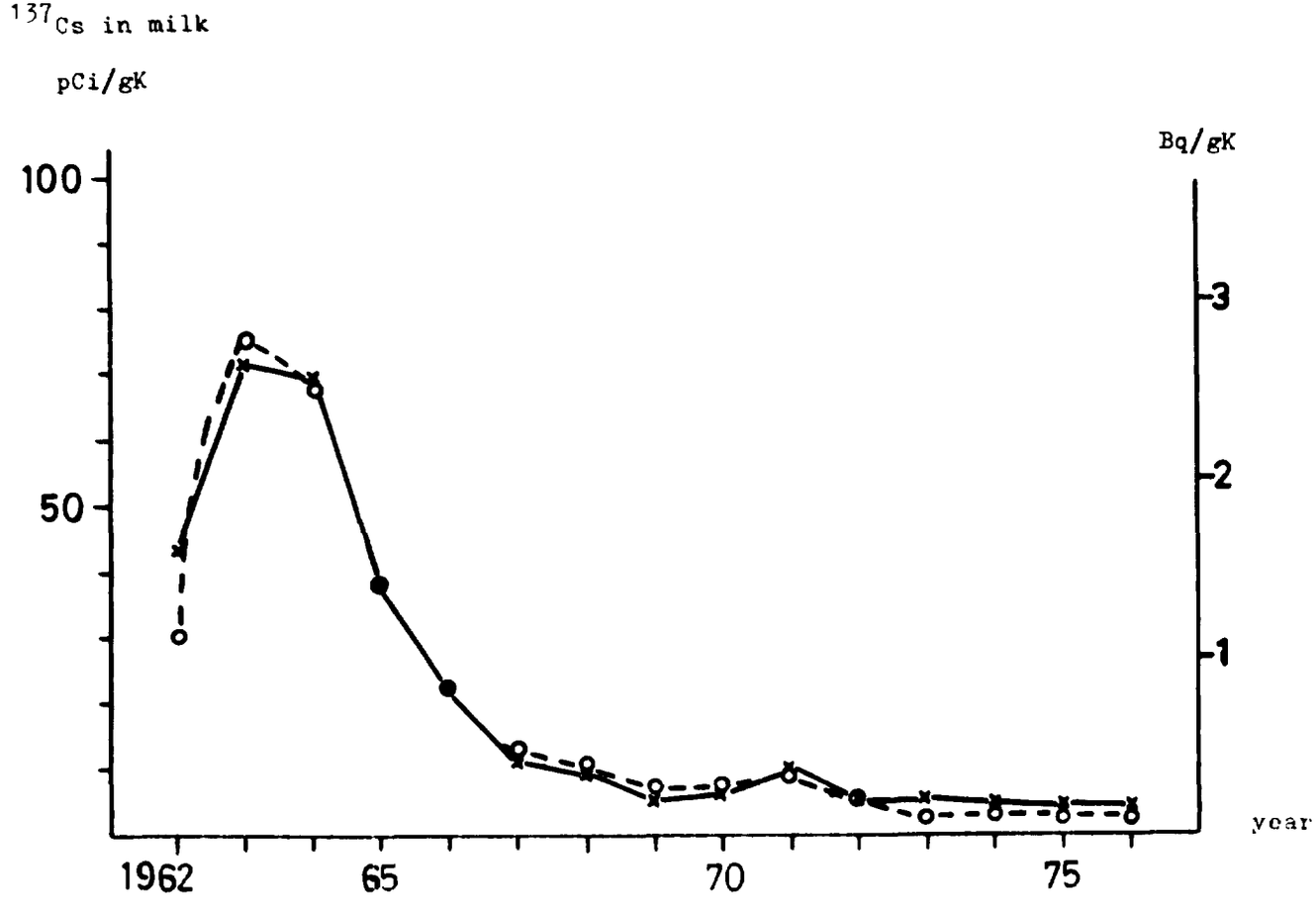
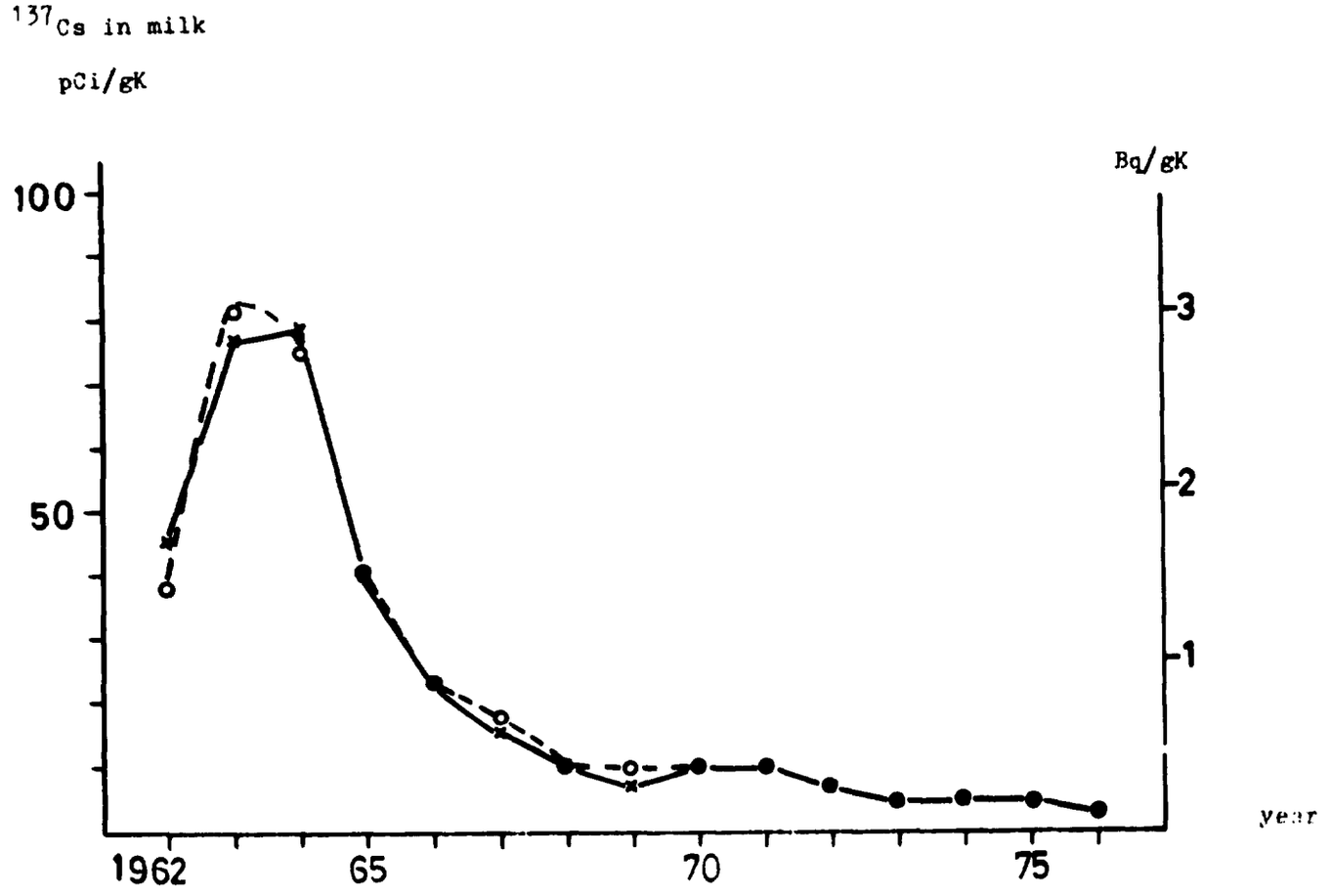


Fig.3 Comparison between the computed values of ^{137}Cs activity in milk from Stockholm and the measured values.

x= the measured activity in milk
o= the computed activity in milk



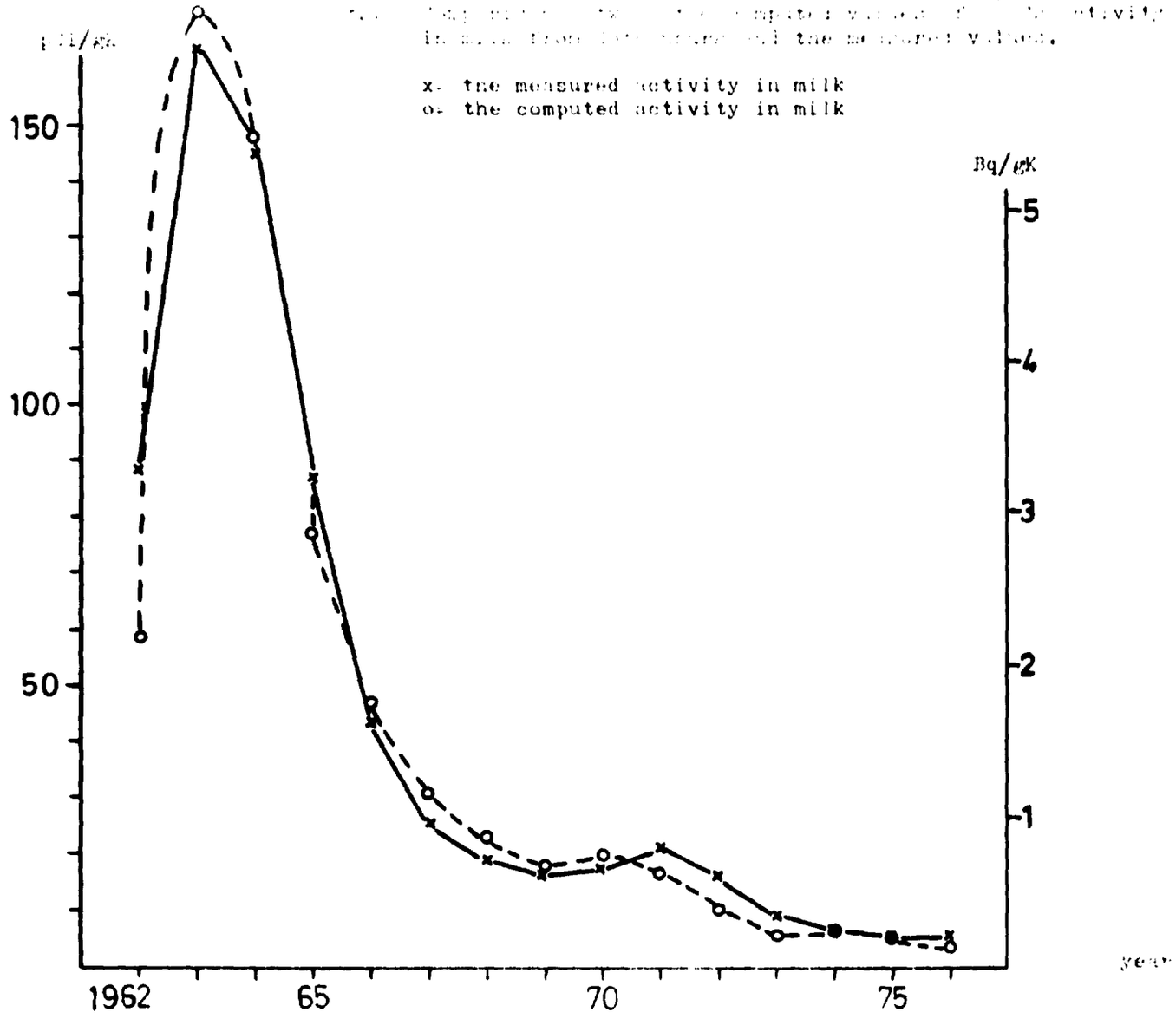

x- the measured activity in milk
o- the computed activity in milk
150
100
50
Bq/ℓK
5
4
3
2
1
1962
65
70
75

Fig.5 Comparison between the computed values of ^{90}Sr activity in milk and the measured values. The values are country wide means.

o = the computed activity in milk
x = the measured activity in milk