Concept of Seasonality in the Light of the Chernobyl Accident*

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Seasonality could have a strong influence on the radiological impact of environmental radioactive contamination. Short-lived radionuclides (*e.g.*, ^{131}I) and those that mainly enter the food chain by direct contamination (*e.g.*, ^{137}Cs) are especially important in this context. In particular, the contamination of cereals is influenced by seasonality. For temperate latitudes it is generally true that radioactive contamination during winter, when the fields lie fallow and the domestic animals are stabled, will result in a significantly lower radiological impact than if a similar contamination were to take place in the summer shortly before harvesting. The impact of the Chernobyl accident on the radioactive contamination of human diet was strongly influenced by seasonality.

Keywords: *Radionuclides; crops; seasonal response; direct contamination*

The impact of a release of radionuclides to the environment on the human food chain depends, among other things, on the time of the year when the release takes place. Seasonality means the varying response to radioactive contamination of environmental samples according to the time of the year when the contamination occurs.

The seasonality factor (S) is the relative standard deviation (RSD) of the monthly time integral concentrations of a given radionuclide in a given sample observed throughout 12 months of a year.

A total deposition of 1 Bq m^{-2} in a month (i) of radionuclide (p) results in an infinite time concentration integral in sample item (a) of I_{ipa} Bq kg^{-1} year.

The variation of I_{ipa} between the 12 months of the year is a measure of the degree of seasonality. This variation is quantified as the RSD, *i.e.*, the RSD of the 12 I_{ipa} values, which have an annual mean of I_m. Hence,

$$S \equiv \text{RSD} = \frac{\sqrt{\dfrac{\sum_{i=1}^{12}(I_m - I_{iap})^2}{(12-1)}}}{I_m}$$

If the RSD > 0, seasonality is present. If the RSD = 0, no seasonality is observed.

The most obvious effects of seasonality are seen in relation to direct deposition on the surface of crops. When the contamination has reached the ground, and indirect systemic contamination (root uptake) becomes the dominant pathway, seasonality is usually no longer relevant. Seasonality is of particular importance in connection with the contamination of cereals.

A deposition event during winter, when the fields lie fallow and the domestic animals are stabled, will result in a significantly lower radiological impact than if a similar contamination were to take place on a mature crop in summer. Seasonality is generally of greater importance in temperate regions than in the sub-tropics where soils can be cultivated throughout the year.

Seasonality should not be confused with seasonal variability. Food products produced throughout the year, *e.g.*, milk, can show seasonal variability, which occurs even though the radioactive deposition is evenly distributed throughout the year. Hence, ^{137}Cs concentrations could be significantly higher in summer milk than in winter milk, if the cows are grazing in summer, but fed with beets during winter[1] (Fig. 1). Permanent pastures could also show a seasonal variation in their radionuclide concentrations owing to variations in the uptake and loss of radionuclides throughout the growing season. In those instances where only seasonal variability is present with no seasonality, the seasonality factor, S, is zero.

Experimental Observations

The effect of seasonality on the contamination of grain has been studied by Middleton[2] and Aarkrog.[3] It appears that the two important factors that influence contamination of the grain are the initial retention and the translocation from the vegetative parts of the seeds. Initial retention is largely independent of which radionuclide is involved, whereas translocation depends strongly on the radioelement.

The fraction of initial intake 3 months before harvest is about 5% of the activity deposited over a field with barley crops, and 1 month before harvest it reaches a maximum of 36%. If the field is contaminated with, for example, ^{137}Cs, 3 months before harvest (1 kBq m^{-2}), the mature grain will contain 2 Bq kg^{-1}; if the contamination occurs 1 month before harvest, 100 Bq kg^{-1} is found in the mature grain (Fig. 2). For ^{90}Sr, the corresponding concentrations would have been 0 and 20 Bq kg^{-1}, respectively, demonstrating that ^{137}Cs is translocated to a much greater extent than ^{90}Sr (Fig. 3).

The highest levels in grain are expected when the contamination takes place in the final month before harvest. The lowest levels will be seen if the fields are contaminated before sprouting.

Chernobyl Experience

In general, the Chernobyl accident confirmed qualitatively the observations on seasonality made before the accident.

With milk (Fig. 4), it was seen that the radioiodine concentrations were low in northern Europe where the grazing season was just beginning, whereas they were significantly higher in southern Europe where the cows had been grazing for months. This latitudinal effect, which is a result of seasonality, was also seen for ^{137}Cs.[4] The effect was most evident for grain (Fig. 5), as was anticipated.

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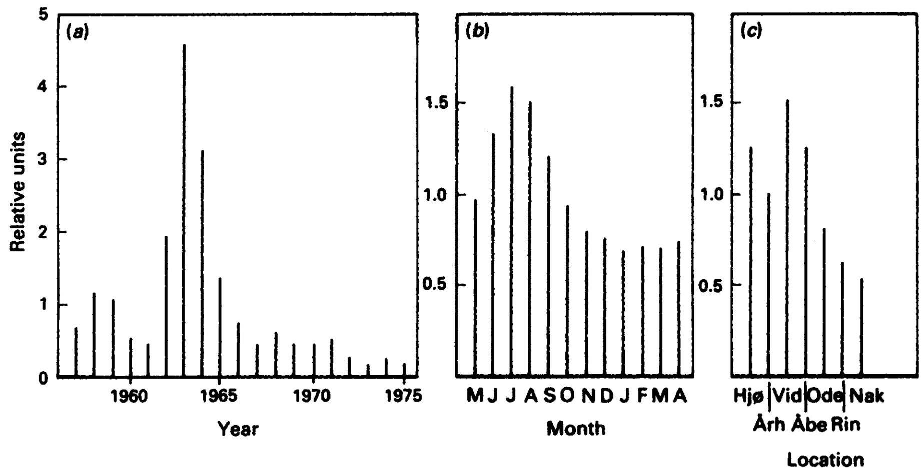

Fig. 1 Variation of ^{137}Cs [Bq (g K)$^{-1}$] in Danish dried milk collected monthly at seven dried milk factories from May 1959 to April 1976. The bars indicate the levels relative to the overall mean, 0.69 Bq (g K)$^{-1}$ (= 1 on the relative scales used)

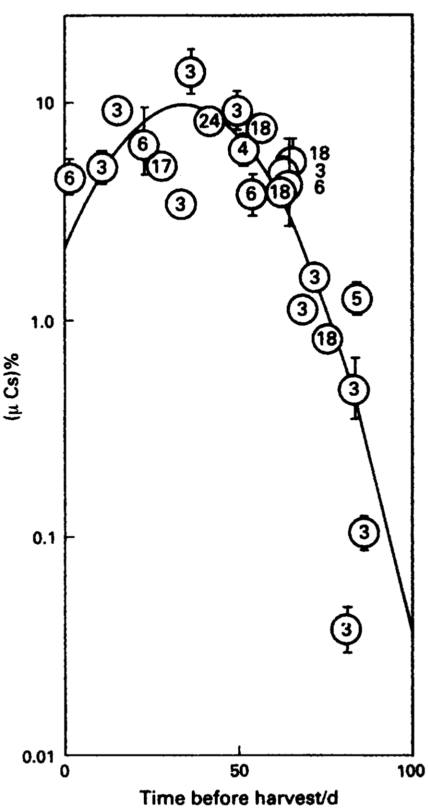

Fig. 2 Percentage (μ Cs) of radiocaesium, applied at various dates to 1 m^2 of a barley field, recovered per kilogram of mature grain at harvest assuming no radioactive decay (number of determinations and 1 standard error are shown). Curve calculated from $\mu(t) = 9.8 \times 10^{-2} e^{-0.0013(t-34)^2}$

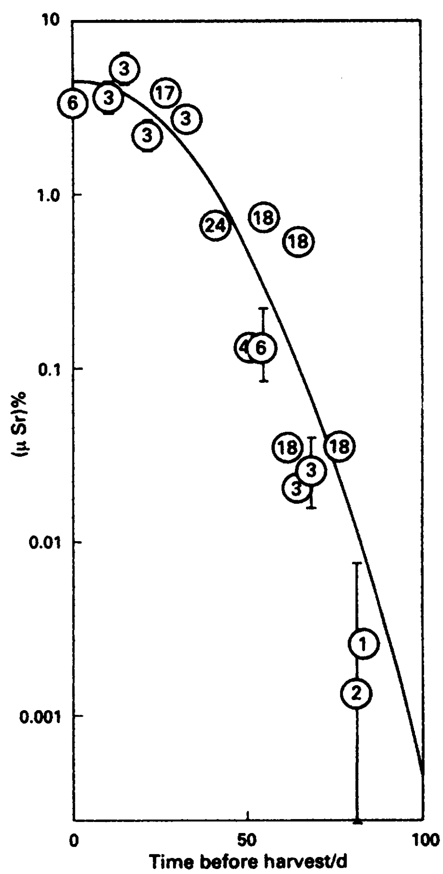

Fig. 3 Percentage (μ Sr) of radiostrontium, applied at various dates to 1 m^2 of a barley field, recovered per kilogram of mature grain at harvest assuming no radioactive decay (number of determinations and 1 standard error are shown) unless the standard error is less than the radius of the circle. Curve calculated from $\mu(t) = 4.5 \times 10^{-2} e^{-0.00095(t-2)^2}$

In Denmark the relative ^{137}Cs concentrations of the grain species (rye, barley, wheat and oats) were compared with those observed in the years before the Chernobyl accident.[5] It appeared that the rye levels were an order of magnitude higher than those seen in the other species after the Chernobyl accident. This observation reflected the precosity of rye compared with that of the other species, resulting in a higher retention of ^{137}Cs by the more developed rye crops when the fallout from Chernobyl was deposited. UNSCEAR[4] calculated the transfer factors (Bq ^{137}Cs kg^{-1} year per kBq m^{-2} ^{137}Cs) in various diets after the Chernobyl accident. It appeared that the factors were usually lower than those observed previously for global fallout of ^{137}Cs, especially for northern Europe. One reason for this was seasonality, which in particular, influences the levels for grain and for which the transfer factors post-Chernobyl were 1–2 orders of magnitude lower than those observed for global fallout. Another reason could be a lower availability of the Chernobyl ^{137}Cs than of that from global fallout with respect to contamination of crops. However, seasonality seems to be the most important factor.

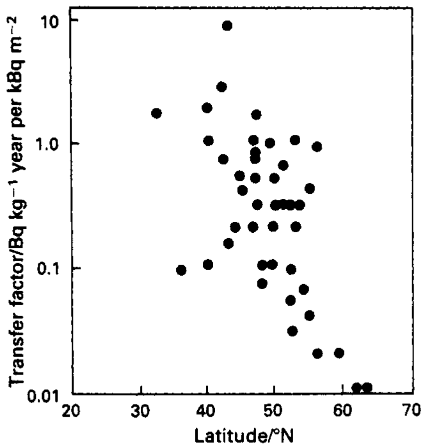

Fig. 4 Integrated concentrations of iodine-131 in milk per unit iodine-131 deposition density. Reproduced from UNSCEAR 1988 (ref. 4)

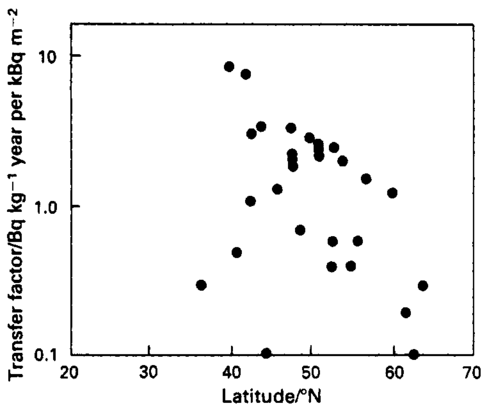

Fig. 5 Integrated concentrations of caesium-137 in grain in the first year after the accident per unit caesium-137 deposition density. Reproduced from UNSCEAR 1988 (ref. 4)

Table 1 Some S values calculated from Voigt *et al.*[6]

	^{90}Sr	^{131}I	^{137}Cs
Milk	0.4	1.1	0.8
Wheat	0.5	2.6	1.9
Root vegetables	0	—	1.2
Leaf vegetables	0.4	0.2	0.5

Application of the Seasonality Factor S

Voigt *et al.*[6] calculated a variety of infinite time integral concentrations (I_{iap} values) (see, *e.g.*, Fig. 6) based on a time-dependent simulation model SINK, which is closely related to the so-called ECOSYS model.[7] These I_{iap} values are site specific for the average conditions in southern Germany and should, therefore, be considered only as examples.

Some S values calculated from Voigt *et al.*[6] are summarized in Table 1.

It is evident (*cf.* Fig. 6) that the degree of seasonality depends strongly on the ratio between root uptake and direct contamination of the crops. If this ratio is low, then seasonality is high and *vice versa*. However, other factors, *e.g.*, translocation of certain radionuclides, also play an important role, in particular for fruit and cereals.

Also, it should be noted that, for certain products, *e.g.*, cereal grain, there could even be monthly seasonality variation, but for practical reasons the definition of the seasonality factor has been based on monthly data.

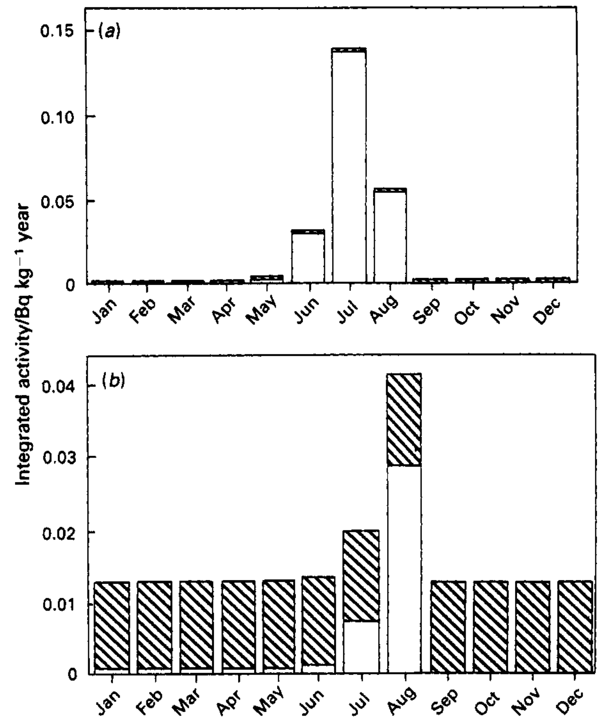

Fig. 6 Dependence of the integrated activity concentration of spring wheat on the month of deposition (shaded part: contribution of root uptake). (*a*) Caesium-137 and (*b*) strontium-90. Reproduced from refs. 6 and 7

Conclusion

Seasonality can have a strong influence on the radiological impact of environmental radioactive contamination. Seasonality is influenced by a number of environmental factors. In the terrestrial soil-to-plant-to-animal system, the ratio of direct to indirect (root uptake) contamination of the plants is of major importance. Seasonality is pronounced if direct contamination is the dominating pathway. The degree of translocation of radionuclides to the fruit bodies of plants also influences seasonality. High translocation normally reduces seasonality. Contamination of cereal grains with ^{137}Cs and ^{131}I shows a pronounced seasonality, whereas ^{90}Sr in root crops shows little or no seasonality.

References

1 Aarkrog, A., D.Sc. Thesis, University of Copenhagen, Risø-R-437, 1979.
2 Middleton, L. J., *Int. J. Radiat. Biol.*, 1959, **4**, 387.
3 Aarkrog, A., *Ecological Aspects of Radionuclide Release*. Special Publication Series of the British Ecological Society, No. 3, 1983, pp. 81–90.
4 UNSCEAR, *Sources, Effects and Risks of Ionizing Radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation, New York, 1988.
5 Aarkrog, A., *J. Environ. Radioact.*, 1988, **6**, 151.
6 Voigt, G., Müller, H., and Pröhl, G., *Experimentelle Verifizierung dynami-Radioökologiemodelle in Folge von Tschernobyl*, GSF-Institut für Strahlenschutz, Neuherberg, GSF-report, 1990, to be published.
7 Pröhl, G., Müller, H., Jacob, P., and Paretzke, H. G., paper presented at the 4th International Symposium on Radioecology, Cadarache, France, March 14–18, 1988, Centre d'Etudes Nucleaires de Cadarache, pp. B43–B50.

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