WOODY BIOMASS PRODUCTION AND RADIOCAESIUM ACCUMULATION RATE IN PINE (*Pinus sylvestris* L.) FROM A CONTAMINATED FOREST IN THE VETKA AREA

Y. THIRY
Radiation Protection Research Unit, SCK-CEN, Boeretang, 200, 2400 Mol, BELGIUM

T. RIESEN
Division for Radiation Protection and Waste Management, PSI, 5232 Villigen PSI, SWITZERLAND

N. LEWYCKYJ
Radiation Protection Research Unit, SCK-CEN, Boeretang, 200, 2400 Mol, BELGIUM

1. Introduction

After the Chernobyl accident, radioactive deposits affected wide forest and agricultural areas in Europe. In Belarus, 23% of the national forest cover are contaminated to radiocaesium levels >37 $kBq.m^{-2}$ (1 $Ci.km^{-2}$). The forest ecosystem as other perennial culture with a high biomass density helps in the long-term stabilisation of the contamination by acting as a reservoir of radionuclides. Nevertheless, the radiocaesium tends to accumulate in the vegetation woody biomass leading to increasing levels of radiopollutants in woody products with time.

In large areas including slightly contaminated forest, nominally those with from 1 to 15 $Ci.km^{-2}$ of ^{137}Cs, wood may be too contaminated for traditional harvesting and processing in a few years. The evolution of this problem which affect more than 1.2 10^6 ha of contaminated forest in Belarus is considered a priority. In this regard, the prognosis on radiocaesium distribution and accumulation in wood are needed to account for the radioecological and economical limitations associated with the future management and economic value of contaminated forest areas.

In this study, we considered a 17 year old scots pine stand located near Vetka (Belarus) and affected by radiocaesium and radiostrontium deposition levels of about 30 and 2 $Ci.km^{-2}$, respectively, following the Chernobyl accident. Our purpose was to investigate the time-trends in cation and radiocaesium distribution in annual rings in order to characterize and quantify the rate of radiocaesium accumulation in trunk biomass as a result of growth.

I. Linkov and W.R. Schell (eds.), Contaminated Forests, 63–70.

2. Materials and method

In December 1997, a sampling trip was made in a pine (*Pinus sylvestris* L.) forest situated near Vetka (Belarus) and contaminated by Chernobyl deposition. We investigated a 17 years old plantation established on a soddy-podzolic sandy soil. The mean surface soil contamination by ^{137}Cs was 1.46 10^6 $Bq.m^{-2}$. The CBH (circumference at breast height) of all trees were measured in three circular plots with a radius of 6 m. Breast height stem sections of scots pine were taken from three freshly cut trees of average circumference category in each plot. To avoid physical or chemical alteration of the fresh wood, each bole section was wrapped in a polyethhylene bag and stored at 4°C. Before the wood samples were extracted for chemical analysis, a 2-cm disc was cut from each bole section with a band saw. The surface of each disk was polished and scanned to reveal annual growth rings. The cross dating was made *de visu*. The mean annual ring width data was obtained from measurement within 0.25 mm along four radii and used to reconstruct the individual dendrochronological curves. The last ring (1997) and outer bark were separated and prepared separately for analysis. Samples of annual tree-rings formed before 1997 were cut off from the half of each disc with a chisel. All fresh materials sampled from wood and bark were weighted and then dried at 105°C for 24h for a dry weight. After burning at 550°C, the ash samples were dissolved in 10 ml of 2N HNO_3. The acid solutions were measured for their ^{137}Cs concentrations using a Ge(Li) gamma-ray spectrometer and the radioactivity was decay-corrected to 26 April 1986. Potassium and calcium content in wood samples were measured from aliquots of acid solutions using of atomic absorption spectrometry.

3. Results and discussion

3.1 STAND CHARACTERISTICS

Figure 1 describes the mean frequency distribution of the trees in the stand as a function of CBH categories. Table 1 shows the mean stand characteristics according to the stand density measured in each plot and to the dendrochronology parameters observed for one tree sampled in the mean CBH category of each plot.

With reference to the English production forecast table for scots pine, the stand belongs to the class 2 (of 6) of fertility with a potential mean annual increment of 12 $m^3.ha^{-1}$. The mean density and height parameters are also in good agreement with those of the mean stand described in the yield table for the same age class.

TABLE 1. Mean stand characteristics

Dendrochronology parameter	*Mean value (standard deviation)*
Height (m)	7.78 (0.55)
CBH under bark (cm)	24.9 (1.7)
Stand density (number trees ha^{-1})	3892 (386)

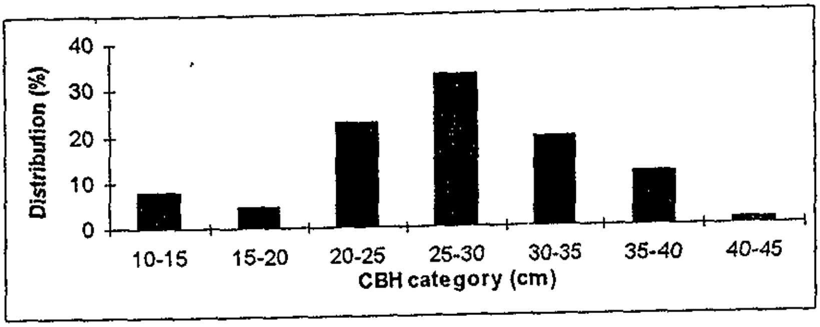

Fig. 1. Mean tree frequency distribution as a function of CBH categories

3.2 QUALITATIVE ASPECT OF THE RADIOCAESIUM AND CATION DISTRIBUTION IN STEM WOOD

The dynamics of radiocaesium and nutrient accumulation in the trunk wood has been studied from extraction and chemical analysis of growth ring samples taken on a stem section sampled at breast height of three representative trees. Figure 2 shows the radial distribution of radiocaesium, potassium and calcium concentrations comparied to the relative water content for each tree.

Between each tree, the discrepancy in element content distribution is very low. The concentrations of ^{137}Cs ranged from 2.5 to 7.5 Bq g^{-1} in the wood formed till 1996, increase drastically in the ring formed in 1997 and decrease in the bark (indicated as 98) (Fig.2). The same general pattern is observed for K and Ca which show comparable mean concentration ranged from 300 to 800 $\mu g.g^{-1}$ in the wood formed till 96. Compared to ^{137}Cs and K, the Ca concentration in bark (4000 $\mu g.g^{-1}$) is however higher than in stemwood (<1997).

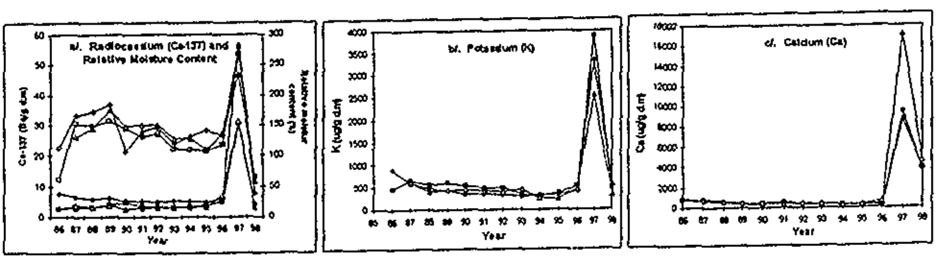

Fig. 2. Radial distribution of (a) radiocaesium, (b) potassium and (c) calcium concentrations in comparison to the relative water content measured in the wood section for each tree

The last ring formed in 1997 shows similarly higher content in all elements than those measured in the previous rings. The similar broad peak for ^{137}Cs, K and Ca concentrations observed in the newly formed ring is also associated with the highest water content. These observations suggest that the cations upward movement follows the transpiration streams which seems mainly restricted to the outermost one annual ring in scots pine. For each stem section, the bark is characterized by similar level of radiocaesium and potassium to the wood formed before 1997. In contrast, calcium shows higher content in bark than in stemwood (<1997). In mature forest stands, the wood contains the main reservoir of K because of its huge biomass, while the bark is the main reservoir for Ca because of its higher concentration in Ca [1]. Our data confirm this observation but the equivalent concentration of K and Ca measured in stemwood show also that the trunk wood of young stand can concentrate similarly both elements. Generalization of element distribution and budgets must be considered with caution and certainly as a function of tree age.

To avoid an effect of changes in wood density with radius in interpretating the cation patterns, the cations content were expressed on a volumic basis. According to the former data expression, figure 3 focus on the mean trends in element concentration for the wood formed between 1986 and 1996.

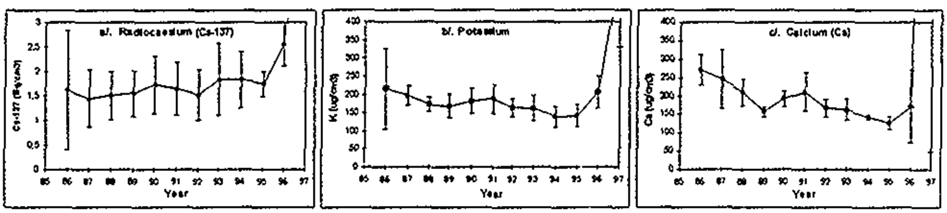

Fig. 3. Mean radial distribution of (a) radiocaesium, (b) potassium and (c) calcium concentrations measured in the wood formed till 1996 and expressed on a volumic basis (Bq cm^{-3} or µg cm^{-3})

In the wood xylem previously formed (1986-1996), the distribution of ^{137}Cs concentration expressed on a volumic basis is uniform with a slight increasing trend in function of radius (Fig.3). By contrast, concentrations of Ca and of K to a lesser extent, decrease slowly from the pith to the outermost rings. In conifers, calcium generally exhibits a decline radial decline from the pith to the cambium while potassium often increases or remains constant [2]. For calcium, it was demonstrated that a steady decline in calcium binding capacity (CBC) with radius can account for the often-observed concentration decrease [3]. For potassium and radiocaesium, a more indefinite trend linked to a high mobility in xylem is a common feature of different trees [4, 5]. This characteristic complicates particularly the historical reconstruction of the radiocaesium uptake. The biochemical behaviour of potassium is however mostly compared to the fate of radiocaesium which shows a comparable mobilization in forest trees [6]. In the wood section studied, the radial pattern observed for ^{137}Cs in the wood formed till 96 is different compared to the monotonous decrease of wood K concentrations. This differential radial pattern shown by ^{137}Cs might thus tentatively be ascribed to an increase of soil radiocaesium availability. An alternative hypothesis is that an increase in ^{137}Cs immobilization in wood could also be the result of a prevailing transient retranslocation phenomenon from the crown to the stem. However, the high ^{137}Cs content in connection with a high water content in the last ring formed supports the assumption of an enhanced uptake from the soil.

3.3 QUANTITATIVE ASPECT OF THE RADIOCAESIUM AND CATIONS DISTRIBUTION IN STEM WOOD

For each wood section, ring width measurements allowed the reconstruction of individual dendrochronological curve. Height and diameter growth data were coupled to calculate the annual volume increment at the scale of the entire bole. According to the assumption of a steady radial distribution of each cation concentration with height, the same calculations were made for ^{137}Cs, K and Ca cations respectively. The comparison between the mean volume growth and the mean cumulative occurrence of ^{137}Cs and of K and Ca in the trunk wood formed before 1996 is shown in figure 4

The ^{137}Cs, K and Ca mean distribution follows the mean volume growth with a comparable exponential function indicating that radiocaesium is also mainly absorbed by roots before to be redistributed and included as the other major nutrients inside the growing trunk biomass. The wood formed till 96 accumulates a total of 43800 Bq of ^{137}Cs but the last formed ring (97) contains more than 40% (i.e. 29700 Bq) of the total activity of the stemwood. In the pine stand studied, the average global ^{137}Cs activity accumulated in the stemwood of the mean tree (86-97) is 73500 Bq. According to the mean activity measured in wood (6540 $Bq.kg^{-1}$) and in soil (1.46 10^6 $Bq.m^{-2}$), the total accumulation of radiocaesium in the trunk is associated with a current mean transfer factor of 4.54 10^{-3} $m^2.kg^{-1}$ which is close to other values estimated for scots pine in similar contaminated forest area in south-east Belarus [7] [8].

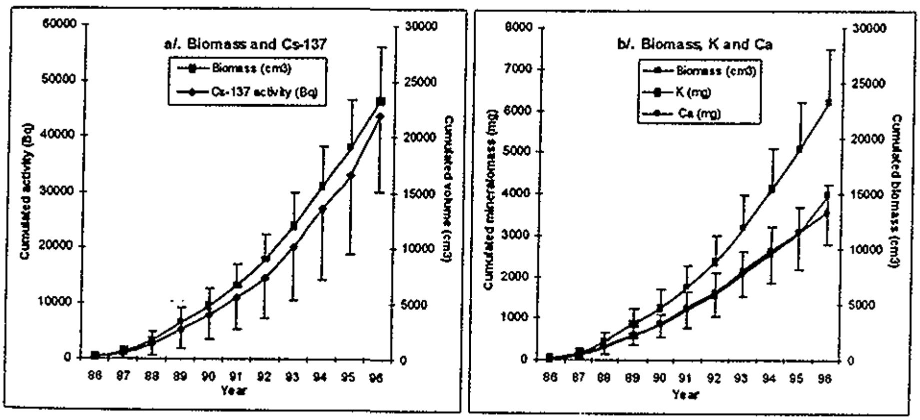

Fig 4.. Comparison between the mean cumulative volume growth (cm^3) and the mean cumulative occurrence of (a) ^{137}Cs and (b), K and Ca measured in the trunk wood formed till 1996

As showed previously, the mobility of cations in xylem can be high and does not allow direct comparisons of the cation concentrations in individual tree rings with historical changes in soil availability, especially for potassium and radiocaesium. However, it was possible to correlate the cumulated amounts of each cation with the cumulated biomass increments that followed an almost simple linear relationship for ^{137}Cs and K as shown in Figure 5.

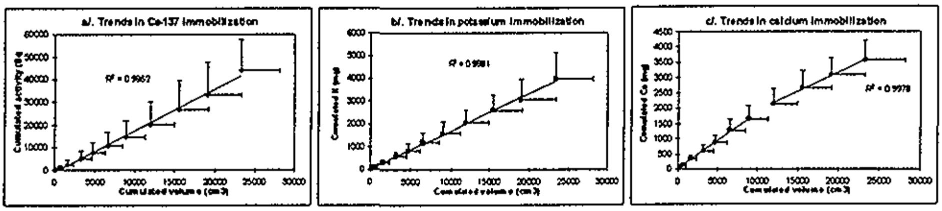

Fig. 5. Relationship between the cumulated annual amounts of (a) ^{137}Cs, (b) K and (c) Ca and the cumulated biomass annual increments in the trunk wood formed till 1996

For Ca, the appearance of a second slope is probably associated with a sharp decrease of the Ca content in the last 5 to 6 rings which represent an important contribution to the volume growth. The slope of the linear regression was estimated and used to deduce a minimal rate of cation accumulation in stemwood as a function of volume growth. For Ca, we considered only the second slope because cumulative calcium fate in the last year of wood formation is undoubtedly more representative for the calcium accumulation in the immediate few years. Table 2 indicates the mean accumulation rate element estimated for individual trees.

In these young trees, the calculated accumulation rate is higher for potassium than for calcium but this trend would be reversed with time as observed in other conifer stands [7] [9]. Because of the biochemical analogy between potassium and radiocaesium, the inevitable accumulation of radiocaesium could be significant especially in young stand.

TABLE 2. Individual and mean calculated values of the accumulation rate of ^{137}Cs, K and Ca

	Annual accumulation rate values in the newly formed biomass		
	Radiocaesium ($Bq\ cm^{-3}$)	Potassium ($mg\ cm^{-3}$)	Calcium ($mg\ cm^{-3}$)
Tree 1	2.27	0.15	0.12
Tree 2	1.64	0.18	0.13
Tree 3	1.51	0.15	0.13
Mean	1.81	0.16	0.13
(St.dev.)	(0.41)	(0.02)	(0.008)

The mean current accumulation rate for ^{137}Cs is estimated at 1.81 $Bq.cm^{-3}$ of new biomass and per year. With reference to the English production forecast table, a similar young pine stands would produce annually 9.9 $m^3.ha^{-1}$ of new biomass. According to the volume growth observed for the last 5 years of the mean trees and according to the mean tree density observed, the current annual volume increment calculated for the stand was 14.8 $m^3.ha^{-1}$. Based on these two different growth estimations, the contamination of the woody compartment of this stand could increase in the next few years from 17.9 to 26.7 10^6 $Bq.ha^{-1}.year^{-1}$, respectively. Till now, the trunk wood compartment of the pine stand had accumulated an average amount of radiocaesium equivalent to 2% of the soil activity. The minimal annual increase in the stemwood contamination should correspond to a soil-to-wood flux ranged between 0.12 and 0.18 $\%.ha^{-1}.year^{-1}$ of the existent soil radiocaesium pool.

4. Conclusions

A dendrochemical approach was performed to reveal the tendency in radiocaesium distribution and accumulation in trunk wood of a young pine stand in connection with the biomass growth yields. It was shown that, as for potassium, the radiocaesium pattern in wood is consistent with a high mobility in pine tree and with a significant accumulation resulting from a prevailing root uptake process. According to a decreasing potassium accumulation in wood of older stands and to a similar feature for radiocaesium, the radiocaesium accumulation process could thus be reduced with time in a growing young stand or in an existing older stand. Until now, only few reference values on radionuclides accumulation in the wood compartment of contaminated forest ecosystems are available in the litterature; these values are mostly used to elaborate generic models in spite of the fact that these data are site-specific.

Nutrient or radionuclide accumulation can not be dissociated from stem biomass which is a cumulative component and is largely age, species and soil dependent. It is thus primordial to multiply such an approach in different edaphic forest types and for different age of tree to provide relevant radiocaesium flux data and to increase our ability to make prognosis using convenient modelling tools.

5. References

1. Duvigneaud, P. and Denayer-De Smet, S. (1973) In: Analysis of temperate forest ecosystems, Reichle, D.E. (Eds.), Springer-Verlag, Berlin, pp 199-224.
2. Arp, P.A. and Manasc, J. (1988) Red spruce stands downwind from a coal-burning power generator: tree ring analysis. Can. J. For. Res. 18:251-264.
3. Momoshima, N. and Bondietti, E.A. (1990) Cation binding in wood: applications to understanding historical changes in divalent cation availability to red spruce. Can. J. For. Res. 20:1840-1849.
4. Kohno, M., Koizumi, Y., Okumura K. and Mito, I. (1988) Distribution of environmental Cesium-137 in tree rings. J. Environ. Radioactivity, 8:15-19.
5. Kudo, A., Suzuki, T., Santry, D.C., Mahara, Y., Miyahara, S. and Garrec, J.P. (1993) Effectiveness of tree rings for recording Pu history at Nagasaki, Japan. J. Environ. Radioactivity, 21:55-63.

6. Ronneau, C., Sombré, L., Myttenaere, C., André, P., Vanhouche, M. and Cara, J. (1991) Radiocésium and potassium behaviour in forest trees. J. Environ. Radioactivity, 14(3):259-268.
7. Dvornik, A.M. and Zhuchenko, T.A. (1994) Predictive model of pine wood contamination (Forestlive). Paper presented at 6th VAMP meeting, Terrestrial Working Group, IAEA, Vienna, November 1994.
8. Thiry, Y., Ronneau, C. and Myttenaere, C. (1992) Comportement du radiocésium en écosystème forestier contaminé lors d'un accident nucléaire. In Proc. IRPA8, Réalisations Mondiales au niveau de la Protection de la Santé du Public et des Travailleurs contre les Rayonnements, Montréal, Canada, May 17-22, Vol II, 1689-1692.
9. Ranger, J., Marques, R., Colin-Belgrand M., Flammang, N. and Gelhaye, D. (1995) The dynamics of biomass and nutrient accumulation in a Douglas-fir (*Pseudotsuga menziesii* Franco) stand studied using a chronosequence approach. Forest Ecology and Management, 72:167-183.