JUSTIFACATION FOR THE SELECTION OF INDICATOR OBJECTS FOR MONITORING ^{137}Cs IN FOREST ECOSYSTEMS UNDER VARYING WEATHER CONDITIONS

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To determine patterns in weather-driven variability of ^{137}Cs accumulation across forest ecosystem components and to justify the selection of indicator objects for radioecological monitoring, a multifactorial analysis was conducted. Consideration of meteorological influences on ^{137}Cs dynamics is important for improving the accuracy and efficiency of monitoring under conditions of long-term radioactive contamination. Based on the results, recommendations were formulated for selecting forest ecosystem components for monitoring.

The analysis was based on data collected at the Paryshiv sampling site (Chornobyl Exclusion Zone). The following meteorological variables were considered: precipitation over different time intervals preceding sampling, air temperature, soil surface temperature, and soil temperature at different depths. The studied components included first- and second-year needles and branches, wood, and outer bark of Scots pine (*Pinus sylvestris* L.), as well as moss (*Dicranum polysetum* Sw.) and soil layers (A_0l, A_0f+A_0h, 0 - 5 cm, and 5 - 10 cm).

The results show that different ecosystem components respond differently to changes in weather conditions. The studied components were therefore grouped into three categories.

The first group includes first-year needles and branches, moss, and the A_0l soil layer. For these components, air temperature plays an important role; however, the strongest relationship is observed with soil surface temperature. This group shows the highest temporal variability. The high sensitivity of first-year needles and branches (R^2 = 0.72 and 0.74, respectively) can be explained by the high metabolic activity of young plant organs. Increasing temperature enhances transpiration, which promotes upward transport of radionuclides via xylem sap. For branches, precipitation is not a critical factor, suggesting that internal transport processes play a dominant role. Although moss is also sensitive to temperature fluctuations, its ^{137}Cs content is mainly controlled by soil surface temperature and precipitation occurring 1 - 3 days before sampling (R^2 = 0.79). Precipitation promotes rapid input or redistribution of radiocesium, while higher soil surface temperatures (0 cm) accelerate drying and contribute to radionuclide retention in moss tissues. In the A_0l horizon, temperature influences microbial activity in the litter, which can either mobilize or immobilize ^{137}Cs (R^2 = 0.81).

The second group includes components that respond strongly to variations in soil temperature at different depths, particularly to warming of the upper soil layer. Second-year needles and branches show moderate sensitivity to air temperature. They respond to both short-term and delayed precipitation, indicating a cumulative effect (R^2 = 0.61 and 0.63, respectively). This suggests that ^{137}Cs accumulation in older plant organs depends on sustained soil moisture availability. Soil temperature at a depth of 5 cm reflects conditions in the zone where most fine roots are located. The upper soil layer (0 - 5 cm) responds to all types of precipitation and soil warming; however, the strongest relationship is observed with soil temperature at 5 cm depth (R^2 = 0.69), while precipitation remains the dominant factor. This pattern may be related to the downward movement of ^{137}Cs from the litter layer into deeper soil layers during rainfall.

The third group includes wood, outer bark, the A_0f+A_0h litter layer, and the 5 - 10 cm soil layer. Wood shows the lowest dependence on weather conditions (R^2 = 0.48). Its ^{137}Cs content is mainly influenced by soil temperature at 10 cm depth and prolonged precipitation. Changes in wood occur with a time lag, as only sustained warming of deeper soil layers leads to noticeable changes in radionuclide concentration. Short-term rainfall has little effect, while cumulative moisture input is more important. Outer bark shows low sensitivity to air temperature but a strong dependence on precipitation occurring 4 - 7 days before sampling (R^2 = 0.54). This can be explained by the accumulation of radiocesium transported along the stem during rainfall (stemflow). For the A_0f+A_0h litter layer and the 5 - 10 cm soil layer, ^{137}Cs content is mainly controlled by soil temperature at 10 cm depth, likely due to enhanced diffusion and vertical movement of water solutions under sustained warming (R^2 = 0.44 and 0.58, respectively). These layers show very low sensitivity to air temperature. Prolonged precipitation remains the main factor controlling radiocesium input into these soil layers.

The analysis also allowed classification of forest ecosystem components according to the influence of meteorological factors on ^{137}Cs content. For needles and branches, both temperature and precipitation are important. For moss and litter, short-term precipitation plays the key role. For wood and deeper soil layers, the main effects are associated with prolonged precipitation and warming of deeper soil layers.

Based on these results, practical recommendations were developed to optimize radioecological monitoring without increasing costs related to sampling, sample preparation, or analysis.

During periods of intensive precipitation and unstable weather conditions (spring and autumn), active redistribution of ^{137}Cs occurs in the upper forest layers. Under these conditions, sampling of the A_0l litter layer and moss is recommended. These components respond rapidly to changes in radionuclide content and can indicate short-term variations in the radiological situation. After heavy rainfall, ^{137}Cs concentrations may change within 1 - 3 days, making these components suitable for rapid assessment of short-term dynamics.

During summer heat and drought, when upper litter layers dry out, microbial activity shifts to deeper soil horizons. Under these conditions, sampling of first-year needles and the 0 - 5 cm soil layer is recommended. First-year needles act as an active pathway for ^{137}Cs accumulation through transpiration. Because this process depends strongly on air and soil surface temperature, changes in radionuclide content in these needles can be used to assess transfer intensity under high-temperature conditions.

Stable summer periods are suitable for assessing ^{137}Cs accumulation in wood. In this case, sampling of wood and soil at 5 - 10 cm depth is recommended. Radionuclide content in these components responds mainly to prolonged warm and moist conditions lasting more than one week. Short-term heatwaves or isolated rainfall events have little effect. Sampling of wood should therefore be carried out no earlier than one week after stable weather conditions are established.

For assessing vertical migration processes, outer bark can be used as an indicator of stemflow. It reflects the transfer of ^{137}Cs from the canopy to the soil during prolonged rainfall, integrating this process over a period of about 7 days.

Conclusions

Based on the analysis of meteorological effects on ^{137}Cs content in forest ecosystem components, the following conclusions can be drawn:

- Moss and the A_0l litter layer are most suitable for rapid gamma-spectrometric assessments.
- First-year needles and the upper soil layer (0 - 5 cm) are sufficient for studying seasonal redistribution.
- Wood provides the most informative indicator for assessing total ^{137}Cs content in forest ecosystems.