Latent Bone Modeling Approach to Estimate Plutonium Activity Concentration in Human Skeleton

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The skeleton is a major depository site for plutonium in a human body. In radiation protection, a long-term standing question is: What is the most accurate and precise way to estimate the skeleton plutonium concentration and activity from the analysis of a limited set of bones? To answer this question, a multiple linear regression was used in several studies. The key limitation of this approach is multicollinearity among independent variables since the activity concentrations from individual bones are highly correlated resulting in unstable and imprecise estimates of model coefficients. In addition, the number of individual bones allowed in a multiple linear regression model is limited, given a very small number of studied cases. Skeleton plutonium activity concentrations (Bq kg^{-1} of wet bone) for 19 whole-body tissue donors to the United States Transuranium and Uranium Registries (USTUR), were estimated based on post-mortem radiochemical analyses of the right side of the skeleton, where the total number of analyzed bones ranged from 72 to 89. At the USTUR, 87% of deceased Registrants are partial-body tissue donors with only 2 to 8 bones collected at autopsy. For these cases, the most commonly collected bones are rib, sternum, vertebral body, patella, clavicle, and femur middle shaft. This study applied principal components regression (PCR) by performing principal components analysis (PCA) on an analytical data set from 19 whole-body cases, followed by the selection of a set of 1 to 3 principal components as latent bones (independent variables) for a subsequent multiple linear regression modeling. Latent bone concentration (C_{lb}) is not directly measured but is a linear combination of individually measured bone concentrations (C_{bone}). Latent bone concentrations, as independent variables in multiple linear regression, are uncorrelated with each other. For rib, sternum, and vertebral body, PCR analysis resulted in the first latent bone equation: $C_{lb1} = 0.5759 \times C_{rib} + 0.5755 \times C_{sternum} + 0.5807 \times C_{vert}$. In this case, the first latent bone alone explained 98.4% of total variance, and the skeleton plutonium concentration can be calculated as $C_{skel} = (18.0 \pm 0.8) \times C_{lb1} + 25.0 \pm 1.4$.

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