Elastic Photon Scattering and Normalization of *In Vivo* XRF Analyses of Pb in Bone

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Abstract:
In recent years in vivo XRF has been found to be an effective aid to occupational health in the monitoring of concentrations of Pb in bone. One popular technique is to site an appropriate source-detector arrangement proximal to the tibial bone. Particularly popular has been use of a relatively high activity point or annular source of ^{109}Cd mounted on the front of a thin-window HPGe detector. XRF excited by source photons at 88.0keV are detected in the backwards direction, the K XRF peaks appearing on the trailing edge of a broad Compton peak, due to the bone and tissue mass, followed by an elastically scattered peak assumed to be due to the Ca and P in bone. The elastically scattered peak is used to normalize the detected K shell fluorescence in order to obtain an analysis in terms of micrograms of Pb per g of bone mineral. In the following simulation of elastic scattering from compact bone (ICRU-37 8-element composition) and soft tissue (ICRU-44 9-element composition) with Pb (at 0, 10, 20, 50, 100, 200, 500 and 100 ppm by mass), we have examined the extent to which Pb concentrations can lead to inaccuracies in the normalization procedure. Our results show that at 10 and 165 degrees, for energies 1-1000 keV, the contribution from Pb to the total elastic scattering sharply increases with increasing photon energy above the K-photoeffect threshold (above about 100 keV), and Pb is more important to the total elastic cross section at 165 degrees than at 10 degrees. For 165-degree scattering and concentrations of 100 ppm, Pb contributes to the total elastic scattering at 88 keV at 0.03% for soft tissue, and 0.01% for bone; at the 1% level in soft tissue by about 150 keV, and in bone by about 250 keV; at the 5% level in soft tissue by about 280 keV, and in bone by about 650 keV.

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Introduction:

In recent years increasing interest has been shown in the application of K-shell x-ray fluorescence (XRF) techniques for the *in vivo* determination of lead in bone (see for instance O'Meara and Chettle, presented at this Meeting). Standardisation is obtained through use of phantoms containing known loadings of Pb. One of the most developed of techniques involves use of a backwards angle scattering geometry in which the various Pb K-shell fluorescence peaks appear on the trailing edge of a dominating Compton peak. The Compton and Rayleigh scattering peaks which are apparent are due to scattering from tissues within the field of view, the elastic scattering peak being a sensitive reflection of the Ca and P composition of bone. Recognition of this has lead to use of the elastic scattering peak in normalisation procedures, the intention being to take account of differences between phantoms and subjects and geometry dependent effects which include subject movement. For tibial bone Pb measurements using a ^{109}Cd source Somervaille et al (1985, 1989) have estimated associated uncertainties of the order of 1- to 2%. Such uncertainty analysis does not take into account the possible effect upon peak intensity of relatively high loadings of Pb in bone, the results of which may depend upon Pb concentration variations. In the present study use has been made of accurate predictions for elastic scattering cross-sections in assessing the possible magnitude of Pb-loading effects.

Methods:

In the present study we have looked at scattering from soft tissues (ICRU-44 9-element composition) with Pb (at 0. 10, 20, 50, 100, 200, 500 and 1000ppm by mass) at scattering angles of 10° and 165°, for photon energies 1 - 1000keV. Use has been made of modified relativistic scattering cross-sections in combination with angle dependent anomalous scattering factors (MSASF) as the basis of the elastic scattering calculations. These form factor approach has been compared with S-matrix predictions at selected energies in the range 1- 1000keV. The MFASF predictions produced reasonably consistent results over the chosen photon energy range, errors being significantly smaller than 30% below 100keV, of the order of 30% for large angles for photon energies of 100 - 200 keV, growing to a factor of 2 at higher energies.

Results:

Plots have been made of the percentage relative difference which are obtained when comparison is made between cross-sections from soft tissue with (CS2) and without Pb (CS1), as follows:

$$\frac{(CS2 - CS1)}{CS1} \times 100\% \qquad (1)$$

For all cases, the relative difference in cross-sections reaches a maximum in the 90 - 200 keV range, above the K-shell photoeffect threshold of Pb. No perceptible enhancement in the ratio right below the edge (where the open subshells for Pb are in the O and P shells); the first dipole allowed transition is a 1s - 6p transition which is very weak. In general for high Z atoms the open transitions from the K-shell will be extremely weak. For 100ppm Pb the relative difference in cross-sections peaks at less than 0.04% around 100keV. For 1000ppm Pb the maximum difference is less than 0.4%.

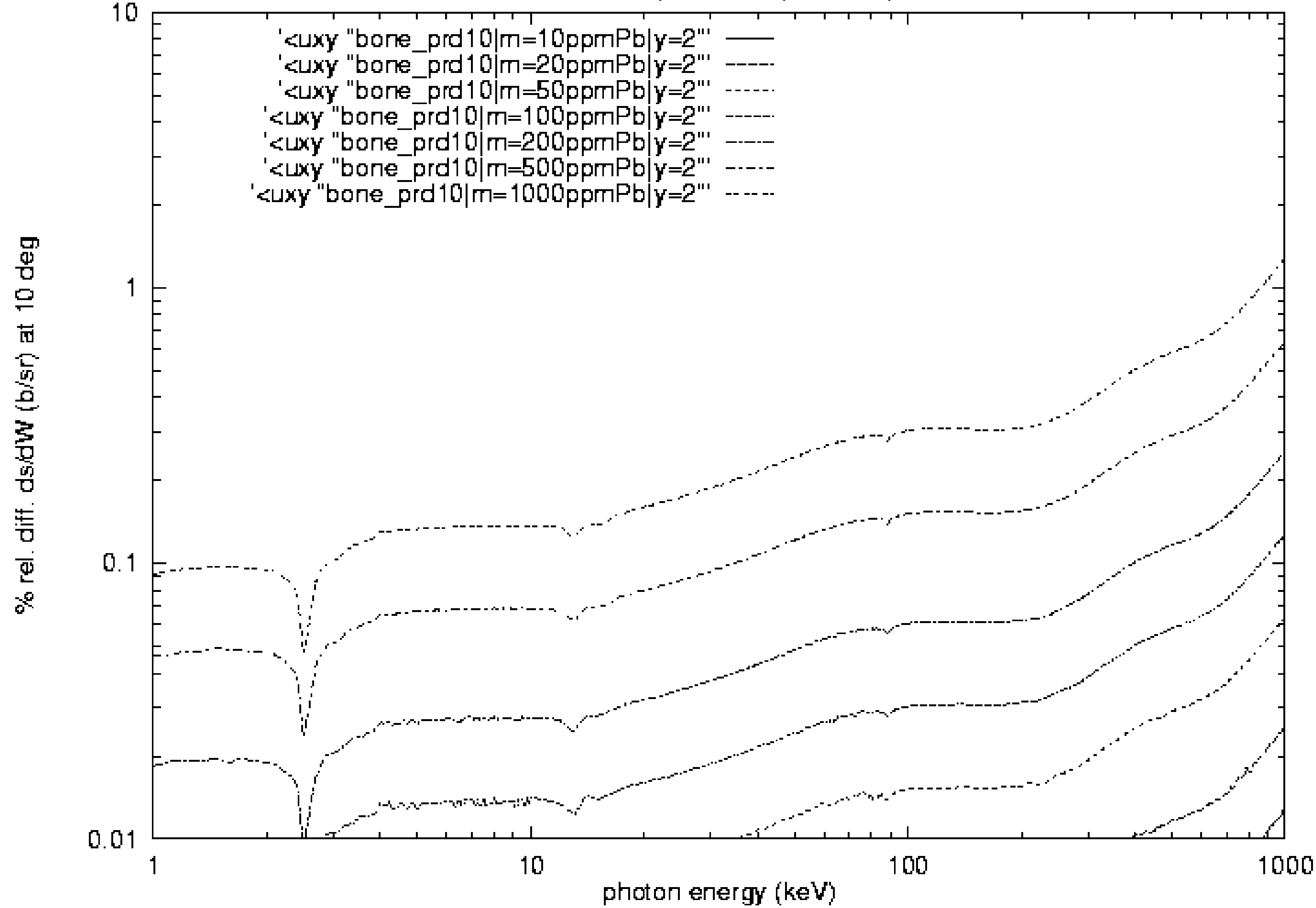
The same calculations have also been made for compact bone using a 6-element model from ICRU-37 . The results don't change materially. The differential cross section plots are rather boring as the differences are reasonably small and the cross sections change by many orders of magnitude over this energy range. Figures 1 and 2 show these results.

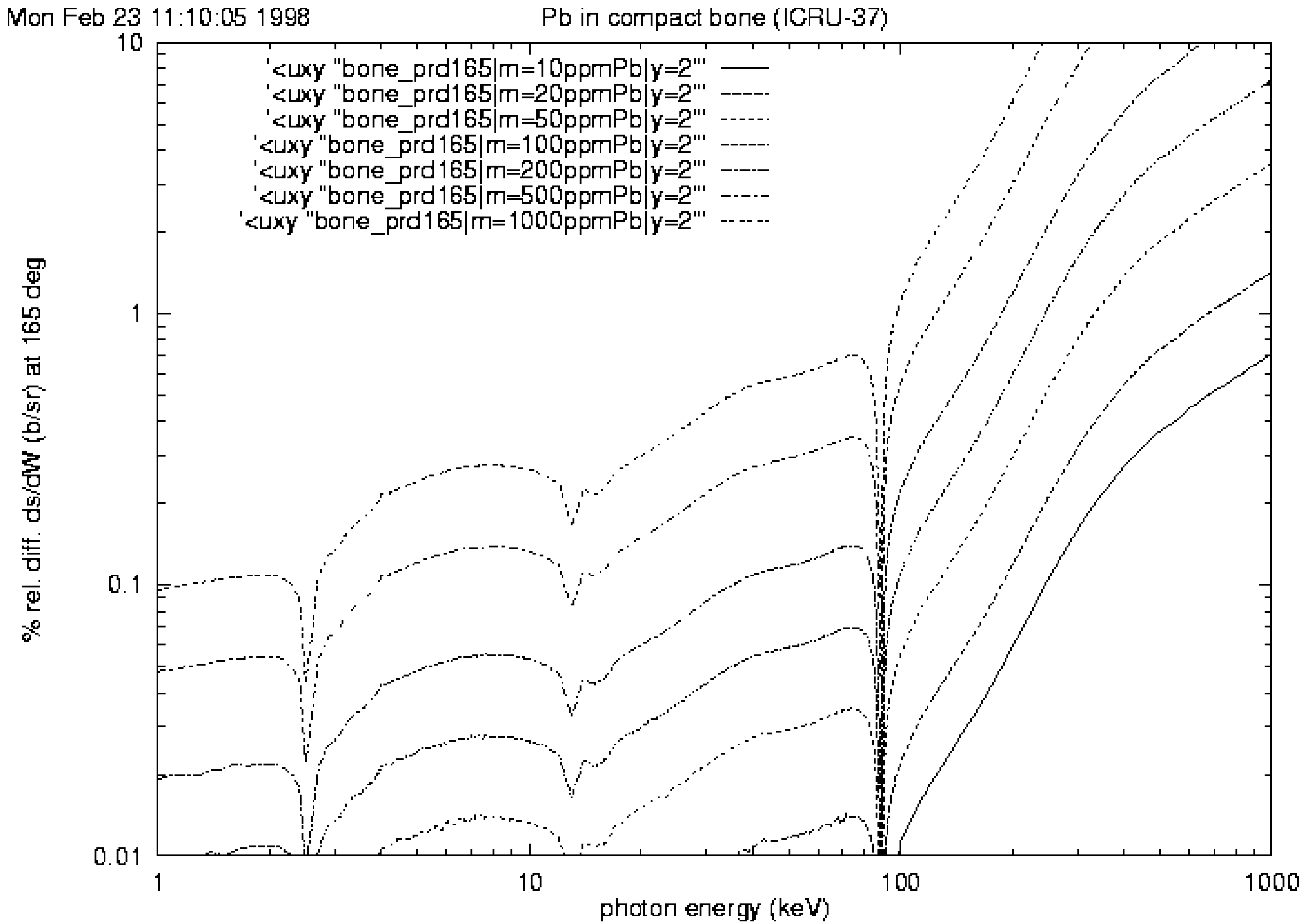
Conclusion:
The normalisation procedure is not affected at the 1% level.

References:

J. O'Meara and D. Chettle. Paper presented at this meeting: Coherent normalisation of 57-Co excited phanlangeal bone lead xrf

Mon Feb 23 11:09:52 1998 Pb in compact bone (ICRU-37)

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% rel. diff. ds/dW (b/sr) at 165 deg
10
1
0.1
0.01
1
10
100
1000
photon energy (keV)