^{41}Ca in Tooth - First Biological Signature of Neutron Exposure of the A-Bomb Survivors in Hiroshima

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We have continued our studies to detect the long-lived radionuclide ^{41}Ca ($T_{1/2} = 103\,000$ years) in tooth enamel to reconstruct thermal neutron exposures of the atomic(A)-bomb survivors of Hiroshima and Nagasaki [1,2,3]. In general, ^{41}Ca is produced via thermal neutron capture on stable ^{40}Ca. Thus, any ^{41}Ca present in enamel of the A-bomb survivors is both due to neutrons from natural sources and from the A-bomb explosion. Tooth samples from large-distant survivors with negligible exposure to A-bomb neutrons were used to investigate the natural ^{41}Ca content in tooth enamel. 16 tooth samples from 13 exposed survivors, all members of the Life-Span-Study cohort, were measured for comparison. For those samples γ-ray doses had already been determined before by means of electron-spin-resonance measurements.

All ^{41}Ca measurements were performed by means of accelerator mass spectrometry (AMS) using the GAMS setup at the MLL. Due to the expected low signals down to naturally occurring levels a dedicated chemical sample preparation was required to produce Calcium hydride from the enamel. In terms of the ^{41}Ca/^{40}Ca isotope ratio, values of about $2{\cdot}10^{-14}$ were found for survivors that had been located close to the hypocenter at the time of bombing, while values as low as $3{\cdot}10^{-15}$ were found for those who survived at larger distances. For those who were not exposed significantly to A-bomb neutrons, the measured ^{41}Ca/^{40}Ca isotope ratios were significantly lower and a mean value of $(1.7{\pm}0.5){\cdot}10^{-15}$ was found. In this work, ^{41}Ca/Ca signals could be distinguished from background for those who were located at a distance of less than 1150 m from the hypocenter, at the time of bombing. Based on the current dosimetry system DS02 [4], the measured background ratio corresponds to a free-in-air neutron dose to the survivors of about 60 mGy.

^{41}Ca/Ca ratios for the exposed survivors show a significant correlation with distance from the hypocenter, similar to that expected from theoretical free-in-air thermal neutron transport calculations. In comparison to the non-exposed survivors, those exposed to A-bomb radiation clearly showed higher ^{41}Ca/Ca isotopic ratios. In addition, decreasing ^{41}Ca/Ca ratios were found in samples with increasing distance from the hypocenter. This decrease with increasing distance are in line with DS02 neutron transport calculations.

As can be inferred from Fig. 1, the calculated ^{41}Ca/Ca ratios [5,4] decrease with increasing distance, from $2.3{\cdot}10^{-14}$ at a distance to the hypocenter of 900 m, to about $3{\cdot}10^{-15}$ at a distance of 1150 m, respectively. In particular cases, the measured data are somewhat higher or lower compared to the calculated ones. Given the fact that the individual surroundings of the survivors were not yet modelled this is not surprising, since neither a potential decrease of the thermal neutrons due to intervening shielding material, nor a potential built-up due to surrounding low Z material such as water that moderates fast neutrons effectively, were adequately included in the model calculations. However, in spite of this shortcoming Fig. 1 demonstrates the measured and the calculated data to follow quantitatively the same trend. A more detailed discussion will require detailed calculations that take into account the modeling of the individual shielding situation. These calculations are presently underway.

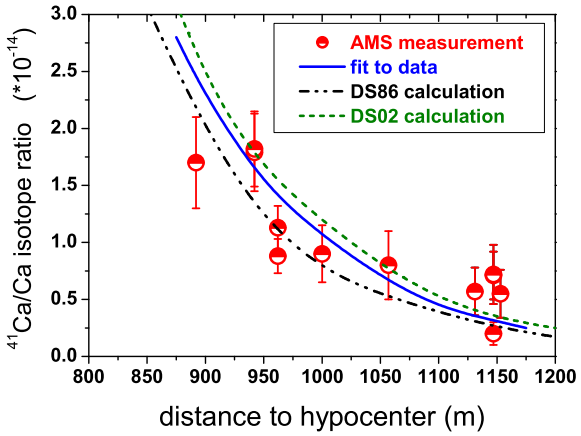

Fig. 1: ^{41}Ca/Ca isotope ratios as a function of distance. Comparison of experimentally obtained ^{41}Ca/Ca ratios (squares) with free-in air calculations (dashed lines; see text). Plotted are AMS results for survivors whose ground range is known.

Thus, for the first time an experimental signature of neutron exposure was found in tissue obtained from A-bomb survivors. Given that for the same samples γ-doses had already been determined before by means of the ESR technique, both components of the mixed field that had been present in Hiroshima at the time of bombing could be - for the first time - quantified in the same biological sample. The results will be useful to reconstruct neutron exposures that were calculated for the survivors on an individual scale, and to validate the assumptions made, e.g. the shielding situation of such survivors.

References

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