^{41}Ca – A Radionuclide 'Baring its Teeth' for Neutron Dosimetry

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The measurement of long-lived radionuclides, produced during the atomic bomb explosions via neutron capture reactions, offers the possibility to asses neutron doses to which the survivors were exposed. For this purpose, one of the most sensitive detection systems - a unique Gas Filled Magnet System (GAMS) [1] - in combination with accelerator mass spectrometry (AMS) is used at the Munich tandem accelerator laboratory. The method applied allows the detection of various radionuclides at natural concentrations and represents a highly sensitive tracing method.

It has been pointed out recently [2], that the production of ^{41}Ca ($T_{1/2}$ = 103 000 years) via thermal neutron capture on ^{40}Ca in tooth enamel may provide a signal which is correlated with the exposure to thermal neutron fluence. There are several reasons which makes tooth enamel particularly suitable as a 'biological dosemeter'. Among those are a) the high concentration of Ca in teeth and b) the fact that the crystaline structure of enamel also allows the use of the electron-spin-resonance-method (ESR) for the retrospective assessment of γ–ray doses [3]. Thus, the detection of ^{41}Ca in tooth enamel would allow, for the first time, an assessment of both, γ–ray and neutron exposures in the same biological material.

To this end, the feasibility of ^{41}Ca-detection in tooth material was investigated thoroughly. Tooth samples from unexposed survivors of the A-bomb explosions have been examined in a first step, in order to determine the overall ^{41}Ca/^{40}Ca background level of the applied method. This is important, if the additional anthropogenic ^{41}Ca signal induced by the atomic-bomb is to be quantified: Fluctuations of the ^{41}Ca/^{40}Ca isotope ratio in natural, i.e. non-exposed samples, are crucial: The natural ^{41}Ca/^{40}Ca concentration has to be constant within a small range, or has to be low enough. Natural concentrations of ^{41}Ca are strongly varying for different geographical areas, namely by two orders of magnitude: A range between $8{\cdot}10^{-16}$ to a few times 10^{-14} was measured for the ^{41}Ca/^{40}Ca isotope ratios (see [4]) in natural samples which were not exposed to atomic-bomb neutrons.

Quantifying such small amounts of nuclides implies an extremely sensitive measurement technique, solely represented by the accelerator mass spectrometry (AMS) technique. The combination of a large accelerator like the MP tandem - and hence providing high ion energies - and our particle detection system [1] fulfilles the requirements for such a study, which include

- a very low detection limit,
- reproducibility in the '10^{-15} region' of isotope ratios,
- high ion currents to allow for sensitive measurements.

The elaborate chemical preparation technique has been retained unchanged (use of Calcium hydride (CaH_2) for AMS). Up to now, we have measured several tooth samples from persons from Hiroshima who were not exposed to atomic-bomb neutrons and can, therefore, be used as control group. The measured ^{41}Ca background is indeed low and confirms our previous expectations (see [2]). The mean of five background samples gives a ^{41}Ca/^{40}Ca isotope ratio of $1.5{\cdot}10^{-15}$ (see dashed line in fig. 1). Additionally, the results obtained on the individual samples were well reproducible and did not significantly differ from the mean.

For comparison, fig. 1 shows calculated ^{41}Ca/^{40}Ca isotope ratios expected in Hiroshima in samples which contain Ca and which were not shielded. The calculation is based on the ENDF/B-VI production cross section, and neutron fluences given in the current dosimetry system DS86 [5] as function of distance from the hypocenter, one meter above ground [5].

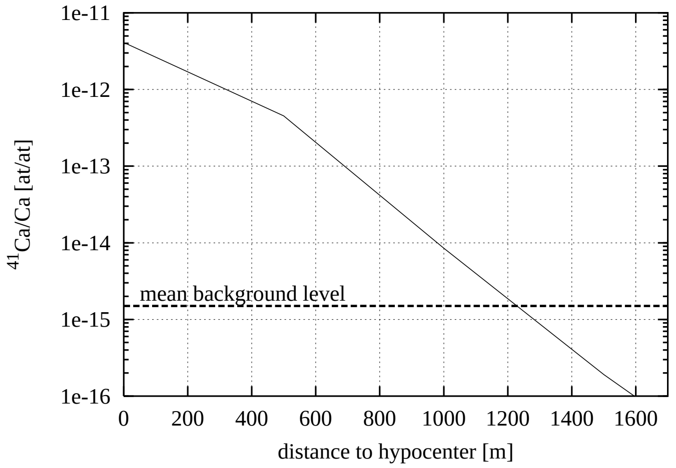

Fig. 1: ^{41}Ca/^{40}Ca isotope ratios as a function of distance. The solid line represents calculations using DS86, the dashed one depicts the mean background level obtained with AMS measurements (see text).

A comparison of the background level obtained for unexposed samples (dashed line in fig. 1) with the calculated ^{41}Ca/^{40}Ca isotope ratio for exposed samples (solid line in fig. 1), indicates that ^{41}Ca might be detectable in enamel from survivors which where exposed up to about 1200 m from the hypocenter. First results for exposed samples, indeed show a significant enhancement of the ^{41}Ca/^{40}Ca isotope ratio.

References

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