Dose Reconstruction for the A-bomb Survivors in Hiroshima: ^{63}Ni as a Monitor for Fast Neutrons

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After the A-bomb explosions in Hiroshima and Nagasaki, a cohort of more than 90,000 survivors was established, in order to study potential health effects (”Life Span Study” (LSS) [1]). Within the frame of the currently valid dosimetry system DS86, individual doses were estimated for each survivor [2]. These dose estimates together with data on late effects from the LSS are used as a basis for currently used risk estimates. Whereas for γ-rays the DS86 computer calculations are in fair agreement with in-situ thermoluminescence data, there are large discrepancies for calculated thermal neutrons fluences and measured thermal neutron activation products like ^{36}Cl or ^{60}Co. In general, DS86 overestimates thermal neutron fluences for short distances from the hypocenter[1] in Hiroshima, and underestimates it for large distances (fig. 1 (a)).

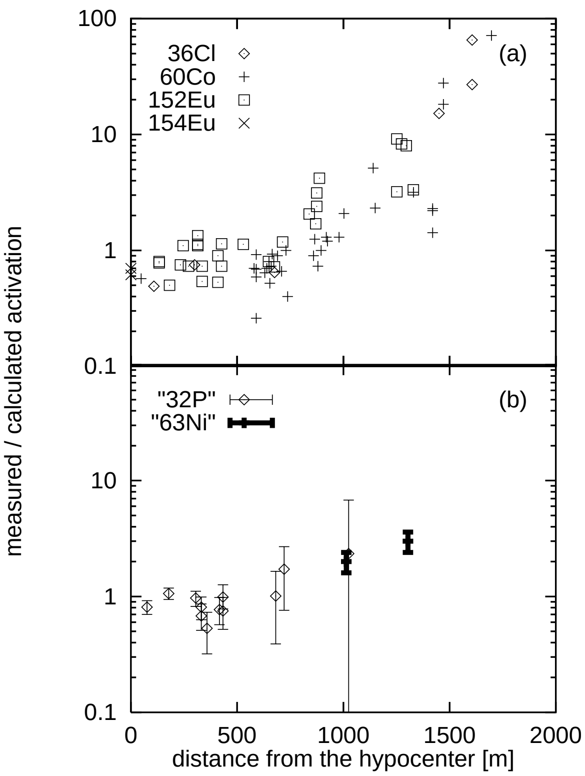

Fig. 1: Ratio between measurements and DS86 calculations of thermal (a) and fast (b) neutron activation products, as a function of the distance from the Hiroshima hypocenter. The bold symbols indicate the data points resulting from the ^{63}Ni measurements in this work. For detailed references see e.g. [3]

The dominant neutron dose, however, is due to fast neutrons. Here, only a limited number of measurements was performed. Immediately after the explosion ^{32}P ($T_{1/2}$ = 14.26 d), produced via ^{32}S(n,p)^{32}P, was detected in the sulpherous glue of insulators [2]. However, for larger distances of the hypocenter which are of high epidemiological relevance, experimental uncertainties are large (see fig. 1 (b)).

Recently, ^{63}Ni ($T_{1/2}$ = 100.1 y) which was produced in copper samples via the reaction ^{63}Cu(n,p)^{63}Ni, was suggested as monitor for fast neutrons [4,5].

This year we improved our sensitivity for ^{63}Ni at the Gas-filled Analyzing Magnet System GAMS to measure ^{63}Ni by means of accelerator mass spectrometry (AMS), which was reported last year [6]. With the presently achieved detection limit of ^{63}Ni/Ni$\approx 3 \times 10^{-14}$ it has become possible for the first time to measure a fast neutron activation product in Hiroshima at distances of 1,500 m and more.

From two Hiroshima copper samples, a lightning rod at 1,014 m and a rain gutter at 1,304 m from the hypocenter, nickel has been extracted at the Lawrence Livermore National Laboratory (LLNL) by electrolysis and nickel tetracarbonyl process, a procedure especially developed for this purpose [7]. The Ni/Cu ratios in the samples were measured by means of atomic absorption spectroscopy at LLNL (about 10 ppm, respectively), the ^{63}Ni/Ni ratio by AMS.

For the 1,304 m sample ^{63}Ni/Ni= $(6.3 \pm 1.1) \times 10^{-13}$ has been measured in Munich which corresponds to ^{63}Ni/Cu= $(1.25 \pm 0.25) \times 10^{-17}$. The result for the 1,014 m sample was ^{63}Ni/Ni= $(2.1 \pm 0.5) \times 10^{-12}$, which corresponds to ^{63}Ni/Cu= $(2.7 \pm 0.8) \times 10^{-17}$. A background level of ^{63}Ni/Ni$\approx 3 \times 10^{-14}$ was achieved, which is about one order of magnitude lower compared to the detection limit at LLNL. Three aliquots of the 1,014 m sample were measured at the Livermore FN tandem with a multi-ΔE chamber. The resulting ^{63}Ni/Cu ratio of $(3.7 \pm 0.5) \times 10^{-17}$ is in good agreement with our data.

Compared to the predictions of DS86, our ^{63}Ni measurements indicate that the actual neutron doses the survivors were exposed to, might have been larger by a factor of about 2 at 1,014 m, and of about 3 at 1,304 m (see fig. 1b).

References

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[1] Hypocenter is defined as the vertical projection of the point of explosion to the ground.