Dose Reconstruction for the A-Bomb Survivors in Hiroshima with the Fast Neutron Monitor ^{63}Ni

T. Faestermann, A.M. Kellerer [a], K. Knie [a], G. Korschinek, A.A. Marchetti [b], J.E. McAninch [b], W. Rühm [a], G. Rugel [a], T. Straume [c], and C. Wallner

[a] Institut für Strahlenbiologie, Ludwig-Maximilians-Universität München

[b] Lawrence Livermore National Laboratory [c] University of Utah

Currently used risk estimates for radiation exposure are based on the data of the Life Span Study (LSS) [1] for the survivors of the atomic bomb explosions in Hiroshima and Nagasaki. This study is the only epidemiologic study where many people were exposed to a mixed field of γ- and n- radiation. In the present dosimetry system DS86 [2] it is assumed that in both cities the dose to the survivors is mainly due to γ-radiation. After the release of DS86 in 1987, however, measurements have shown that DS86 may substantially underestimate *thermal* neutron fluences at large distances ($>$ 1000 m) from the hypocenter[1] in Hiroshima (see for example [3]). This discrepancy casts doubts on neutron doses estimated to the survivors. Neutron doses are caused mainly by *fast* neutrons. The existing measurements on fast neutrons, i.e. the measurement of ^{32}P produced by fast neutrons via the reaction ^{32}S(n,p)^{32}P are not meaningfull at large distances [2,4], due to large measurement uncertaincies. To determine retrospectively fast neutron fluences in Hiroshima and Nagasaki the reaction ^{63}Cu(n,p)^{63}Ni can be used, if adequate copper samples are available [5,6]. By means of AMS with the gas-filled-magnet GAMS we are able to determine concentrations as low as 10^4 at/g Cu typical for distant samples. The method of is described in detail in [4,7,8,9].

Several improvements have been made aiming at a better quality of the measurements. Most important by a new generating volt meter(GVM) [10]. Together with an overall refurbished charging system we achieve now a stability of the tandem voltage better than 1 kV.

The dedicated ion source, developed for ^{63}Ni [8] has been tested for cross talk. The cross contamination level obtained was less than 10^{-5} for ^{63}Ni, which can easily be tolerated.

Nickel has been extracted from the copper samples at the Lawrence Livermore National Laboratory (LLNL) by electrolysis and a nickel tetracarbonyl process, which was developed especially for this purpose [11].

For quality control a piece of copper wire irradiated with a calibrated ^{252}Cf source was analyzed. Depending on the cross section library used, i.e. ENDF/B-VI or JENDL-3 the calculated ratio of the final sample was 0.87×10^{-11} or 1.09×10^{-11}, respectively. We determined a ratio of $(1.0 \pm 0.1) \times 10^{-11}$. In a blind test we determined the ^{63}Ni/Ni ratio in a sample prepared at LLNL to be $(3.5 \pm 0.6) \times 10^{-13}$. The precise value was ^{63}Ni/Ni $= 3.6 \times 10^{-13}$. A background level of ^{63}Ni/Ni$\approx 2 \times 10^{-14}$ was achieved.

Our samples from Hiroshima were in line of sight of the explosion. Results for a lightning rod from the old city hall of Hiroshima (1014 m from hypocenter) obtained at Munich and LLNL are consistent within the given uncertaincies. Another sample was from a rain gutter from the roof of the elementary school of the Hiroshima University (1304 m from hypocenter). The sample was measured only in Munich due to the low detection limit achieved. The results obtained at different beam times were consistent(table1).

Copper Samples from Hiroshima	^{63}Ni/Cu [10^5 at/g]
Hiroshima City Hall, 1014 m	
aliquot 1 [9/98]	1.7±0.6
aliquot 2 [9/98]	2.6±0.7
aliquot 3 [7/99]	2.7±0.4
Hiroshima University Elementary School 1304 m	
aliquot a [9/98]	1.2±0.2
aliquot b [7/99]	1.2±0.3
aliquot c [7/99]	1.1±0.2

Table 1: Measurements of the fast neutron fluences at 2 locations. Different measurements show a good agreement. The errors are statistically $\pm 1\sigma$. In parenthesis: date of measurement.
Note: results are not decay corrected.

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