Uncertainties of DS86 and Prospects for Residual Radioactivity Measurement

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Residual radioactivity data of 152Eu, 60Co and 36Cl have been accumulated and it has been revealed in the thermal neutron region that a systematic discrepancy exists between the measured data and activation calculation based on the DS86 neutrons in Hiroshima. Recently 63Ni produced in copper samples by the fast neutron reaction 63Cu(n,p)63Ni has been of interest for evaluation of fast neutrons. Reevaluation of atomic-bomb neutrons and prospects based on residual activity measurements have been discussed.

INTRODUCTION

A new dosimetry system DS86 has been assessed in 1987 for survivors of Hiroshima and Nagasaki atomic bombs. In the evaluation of low-energy neutrons, a systematic discrepancy between 60Co data1) measured by Hashizume et al and activation calculation based on the DS86 neutrons was found in both cities. Figure 1 shows the discrepancy of 60Co for rebars embedded at the depth of 8 cm in concrete. This problem, however, was not clarified at that time. 152Eu data measured both in Hiroshima and Nagasaki are shown in Fig. 2 and 3, but did not have enough accuracy to examine the calculation. Thereafter, residual radioactivity 152Eu, 60Co and 36Cl data were accumulated and a systematic discrepancy between the measured data and the neutron activation calculation was revealed in Hiroshima. Recently, a new approach to evaluate fast neutron fluence has been pointed out by measuring 63Ni produced through the 63Cu (n,p) 63Ni reaction. Copper samples were collected and measurements of 63Ni are in progress.

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Fig. 1. Calculated to measured ratio of $^{60}$Co activities\textsuperscript{1}.

Fig. 2. Comparison of measured and calculated $^{152}$Eu activity in Hiroshima\textsuperscript{1}.
MATERIALS AND METHODS

Depth profile in rocks

Direct fast neutron evaluation of A-bomb has been performed based on the data of $^{32}$P (half-life $T_{1/2}$=14.3 d) measured immediately after the bomb. An indirect way to estimate the neutron spectrum is to measure the depth profile of $^{152}$Eu in massive rocks. Energetic neutrons incident on the rock surface lose their energy through scattering with the rock elements until they reach thermal energy. Thermalized neutrons induce $^{152}$Eu along their path in the rock. Thus, the depth profile reflects the incident neutron spectrum. A granite core sample of Motoyasu Bridge pillar (MP1) was obtained at 132 m from the hypocenter and the depth profile of $^{152}$Eu was measured. Calculation of $^{152}$Eu in Motoyasu Bridge has been performed. Moreover, two granite cores and two concrete core samples were obtained within 500 m from the hypocenter of Hiroshima. Those samples were granite core of Motoyasu Bridge pillar (MP2) which is located at 101 m from the hypocenter and just on the river bank, granite core of Shirakami Shrine (SS core) at 478 m from the hypocenter, concrete core of Gokoku Shrine (GS core) and concrete core of Hiroshima Bank (HB core).

Kato et al. have measured depth profiles of $^{152}$Eu and $^{36}$Cl in a granite tombstone located at 107 m from the hypocenter. $^{152}$Eu profile was measured by Ge(Li) detector and $^{36}$Cl profile was
by the accelerator mass spectrometry (AMS) in Munich.

Nakanishi et al\textsuperscript{5}) have measured the $^{152}\text{Eu}$ depth profile in core samples of Fukoku Life Insurance Co. Ltd. at 320 m from the hypocenter which was composed of 10 cm granite, 5 cm concrete and 7.5 cm reinforcing concrete.

In Nagasaki, $^{152}\text{Eu}$ depth profiles were accumulated by Tatsumi-Miyajima and Okajima\textsuperscript{7)}. They extracted cores from river bank stones within ground distance about 30–300 m.

Residual activity measurement in Hiroshima and Nagasaki

In Hiroshima, residual activity data of $^{152}\text{Eu}$ in rocks, tiles and rooftop tiles were accumulated by Nakanishi et al\textsuperscript{8)} and Shizuma et al\textsuperscript{9)} within 1500 m slant range. Chemical separation was performed to enrich the europium concentration and gamma-ray measurements were performed with low-background Ge detectors. $^{60}\text{Co}$ data were accumulated by Kerr et al\textsuperscript{10)} and by Kimura et al. They measured samples of handrails of Chugoku Electric Co. smokestack located at 883 m slant range and Yokogawa Bridge 1415 m slant range. Shizuma et al\textsuperscript{11)} measured $^{60}\text{Co}$ simultaneously with $^{152}\text{Eu}$ in six mineral samples collected near the hypocenter. They also measured $^{60}\text{Co}$ in six steel samples up to 1793 m slant range. Chemical separation was performed to extract cobalt. Haberstock et al and Straume et al\textsuperscript{12)} obtained $^{36}\text{Cl}$ data using AMS method.

In Nagasaki, Shimazaki and Okumura reported $^{152}\text{Eu}$ and $^{60}\text{Co}$ data indicating a similar discrepancy as Hiroshima. Straume et al\textsuperscript{13)} measured $^{36}\text{Cl}$ from samples collected at three locations in Nagasaki. Recently, Nakanishi et al\textsuperscript{14)}, reported 5 data at 1100–1200 m in Nagasaki. They reported an agreement with calculation. Shizuma et al collected rock samples in Nagasaki within 1000 m from the hypocenter. Their sample preparation and measurements are in progress.

$^{63}\text{Ni}$ measurement

Recently, Shibata et al\textsuperscript{15)} have proposed a new method to evaluate the fast neutron component of the atomic bomb by measuring $^{63}\text{Ni}$ ($T_{1/2}=100\text{y}$) produced by the fast neutron reaction $^{63}\text{Cu}(n,p)^{63}\text{Ni}$ in copper sample. Since $^{63}\text{Ni}$ emits only low energy beta-rays, it can be measured by the liquid scintillation method or the AMS method. Several copper samples were collected in Hiroshima: electric wire existed inside of the Motoyasu bridge pillar (GR = 132 m), lightning conductor of City Hall (1024 m), rain gutter of radioisotope building of Hiroshima University (1450 m) and lightning conductor of soy source brewery (948 m).

RESULTS

The $^{152}\text{Eu}$ depth profile of Motoyasu Bridge core MP1 and MP2 are shown in Fig. 4. The two distributions are in good agreement; nevertheless the pillar of MP1 was located on the river and that of MP2 was on the river bank. The depth profile of Motoyasu Bridge pillar MP1 core was compared with calculation using MCNP code by Iwatani et al and DOT-MORSE coupling technique by Imanaka. Both calculation gave almost the same results and they indicated that the actual neutron spectrum was softer than the DS86 neutron spectrum.

The measured $^{152}\text{Eu}$ and $^{60}\text{Co}$ activities as a function of distance were compared with activa-
Fig. 4. Depth profiles of $^{152}$Eu in granite cores MP1 and MP2 extracted from the Motoyasu Bridge pillars.

Fig. 5. Calculated to measured ratios of $^{60}$Co, $^{152}$Eu and $^{36}$Cl in Hiroshima.

DISCUSSION

Hiroshima

The $^{152}$Eu depth profile data measured to a depth of 40 cm from the surface of cores within...
500 m from the hypocenter indicate that the incident neutron spectrum is rather soft compared to the DS86 neutron spectrum.

Recent $^{60}$Co data of steel samples up to 1700 m from the hypocenter support the previous Hashizume’s $^{60}$Co data. The C/M ratio for $^{60}$Co as a function of slant range agrees with those of $^{152}$Eu and $^{36}$Cl. The residual activity data as a function of distance indicate that the incident neutron spectrum is harder than the DS86 neutron spectrum, whereas the depth profile data indicate softer. Both data must be explained consistently. In Hiroshima, the discrepancy is possibly related to a) the burst height of the bomb, b) the bomb yield, c) the neutron transport calculation in the air-over-ground geometry and d) the neutron source spectrum originating from the bomb assembly.

**Nagasaki**

The $^{152}$Eu depth profiles were classified according to the fact whether they faced to the epicenter; however, no large difference were found. Up to now, all measured data of $^{152}$Eu, $^{60}$Co and $^{36}$Co are not definitive as to whether the systematic discrepancy between the measured data and calculation exist in Nagasaki or not. Further measurements are necessary to solve the discrepancy problem.

**Prospects**

A key to solve the discrepancy problem is whether such discrepancy exists in Nagasaki. If the discrepancy also exists in Nagasaki, the discrepancy problem will be attributed to the neutron transport calculation. If not, the problem will be confined only to the Hiroshima source spectrum.

Fast neutron reactions $^{63}$Cu(n, p)$^{63}$Ni and $^{63}$Cu(n, α)$^{60}$Co are promising to evaluate fast neutron fluence. Measurements of $^{63}$Ni for several copper samples are in progress both by AMS and beta-ray spectrometry. Evaluation of neutron source spectrum and cross sections which are also important in transport calculation will be continued to solve the discrepancy problem.

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