Chapter 5 Appendix 6

QUANTITATIVE MEASUREMENT OF THE DEPTH DISTRIBUTION OF ^{152}Eu ACTIVITY IN ROCKS EXPOSED TO THE NAGASAKI ATOMIC BOMB

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The fluence of fast neutrons which contributes to the kerma in tissue cannot be obtained directly from the neutron-induced activity of ^{152}Eu. However, the nuclide ^{151}Eu is regarded as a highly sensitive neutron detector because of its large thermal neutron capture cross section of 5900 barns at 0.025 eV. That is, with a moderator for fast neutrons, ^{151}Eu can be used as a detector with fast neutron response. Moreover, the sensitivity is controllable by changing the thickness of the moderator so as to detect preferentially neutrons with various energies. Therefore, the incident neutron energy on the rock surface can be estimated by measuirng the change of the activity of ^{152}Eu with increasing depth in rock. To obtain the energy spectra and tissue kerma of Nagasaki A-bomb neutrons, rock cores were taken from the embankments on both sides of the rivers near the hypocenter.

Samples

The locations of 27 core samples of rock which were taken from near the hypocenter in Nagasaki are shown in Figure 1. The activity of ^{152}Eu was measured at six locations, which are indicated with open circles in the figure. All cores were 10 cm in diameter and 20 to 30 cm in length; they were cut into 2.7 cm thick plates. The cutter produced 0.3 cm thick cutting losses. An example is shown in Figure 2. A cross-sectional view of the line A-A' in Figure 1 and the locations of the samples at which the depth distributions of ^{152}Eu activity were determined are shown in Figure 3.

Measurements

A pure germanium semiconductor detector with efficiency of 16% relative to a NaI(Tl)

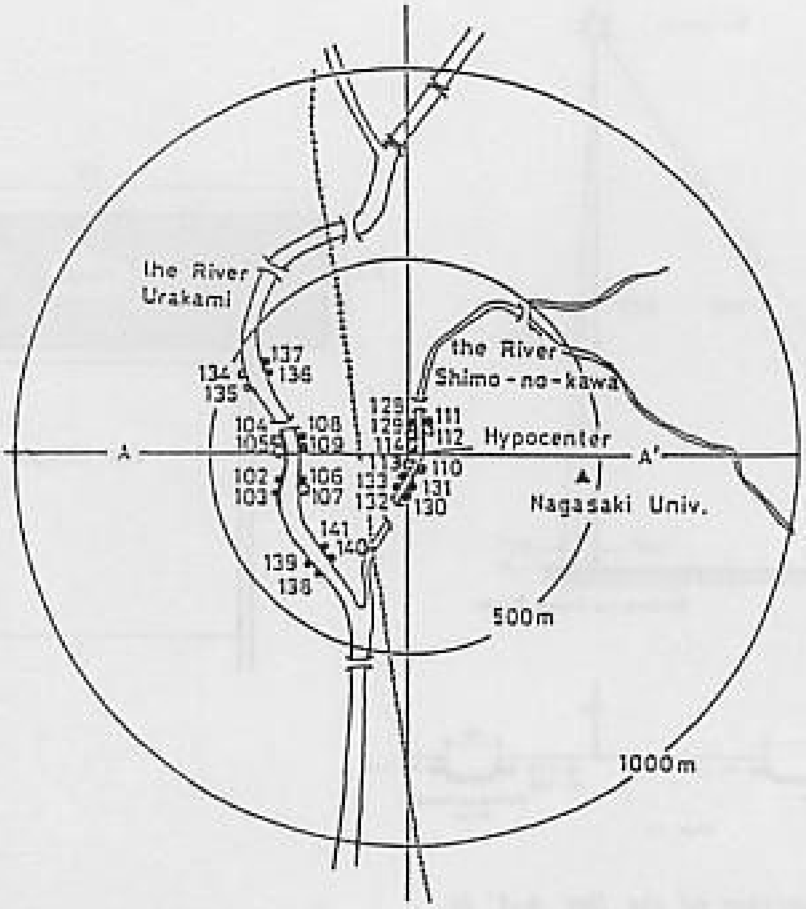


Figure 1. Location of core samples of rock and their relationship to the hypocenter. The open circles mark the positions of samples whose ^{152}Eu activity was measured

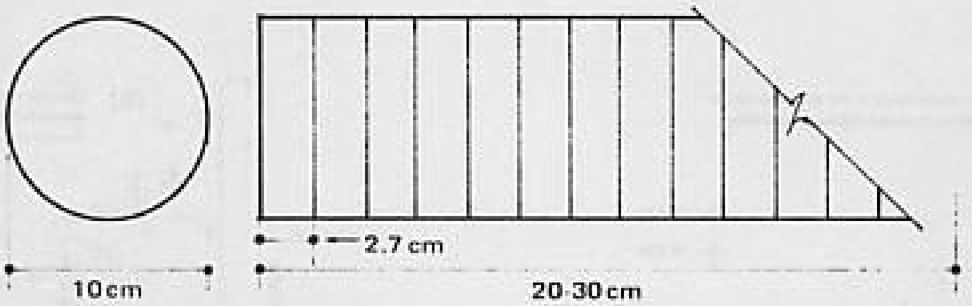


Figure 2. An example of a core sample of rock. All cores where 10 cm in diameter and 20 to 30 cm long and were cut into 2.7 cm thick plates. The cutter produced 0.3 cm thick cutting losses

detector 7.6 cm in diameter by 7.6 cm high was used for the gamma-ray measurements. The detector was shielded by 10 cm lead bricks and a 2 cm thick iron plate on the inner sides. All sections were nondestructively measured as shown in Figure 4. The ^{152}Eu peaks at 122 keV and 344 keV were identified from the gamma-ray spectrum for each core section.

The detection efficiency of the detector was determined by the following procedure. After one of the core sections taken from near the hypocenter was milled, the rock powder was kept in a cylidrical polyethylene container and compared with a control sample of the

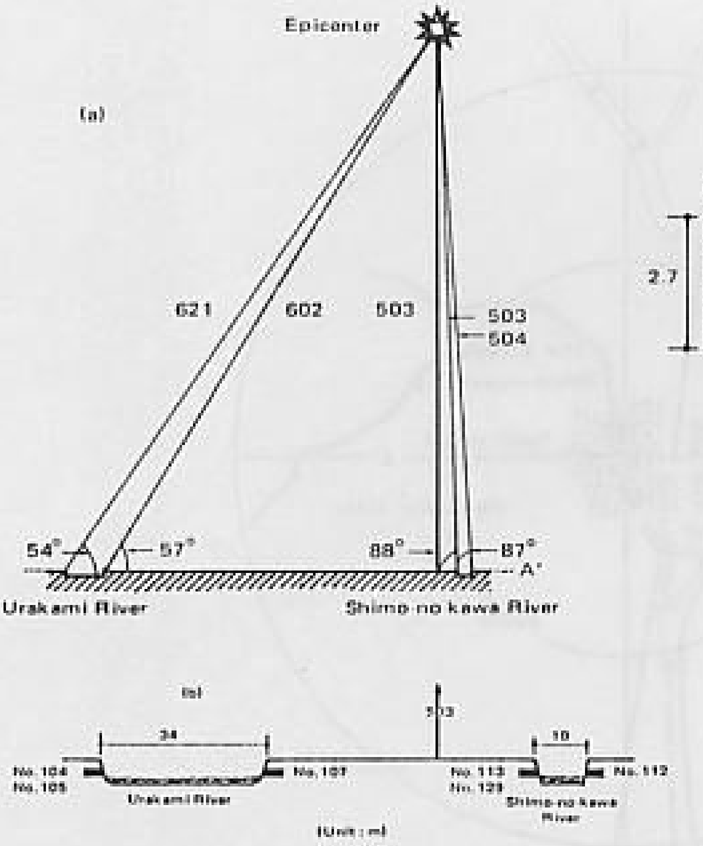


Figure 3. Cross section of the line A-A' in Figure 1 (a) and cross section of the locations of samples for which depth distributions of ^{152}Eu activity were determined (b)

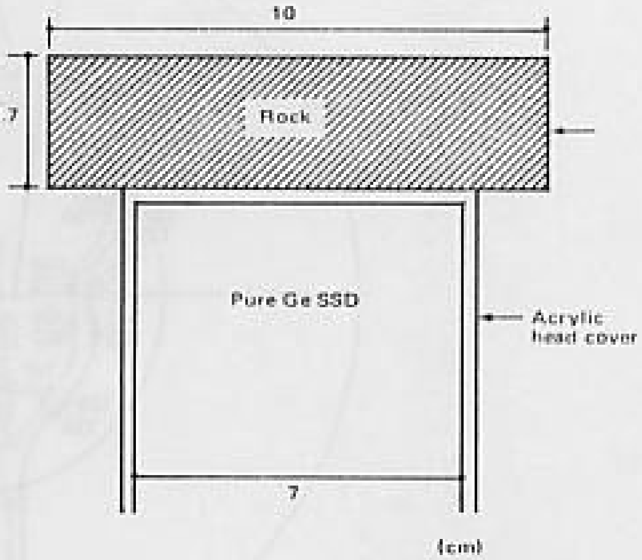


Figure 4. Scheme of the measurement, which shows the rock plate placed on the detector head

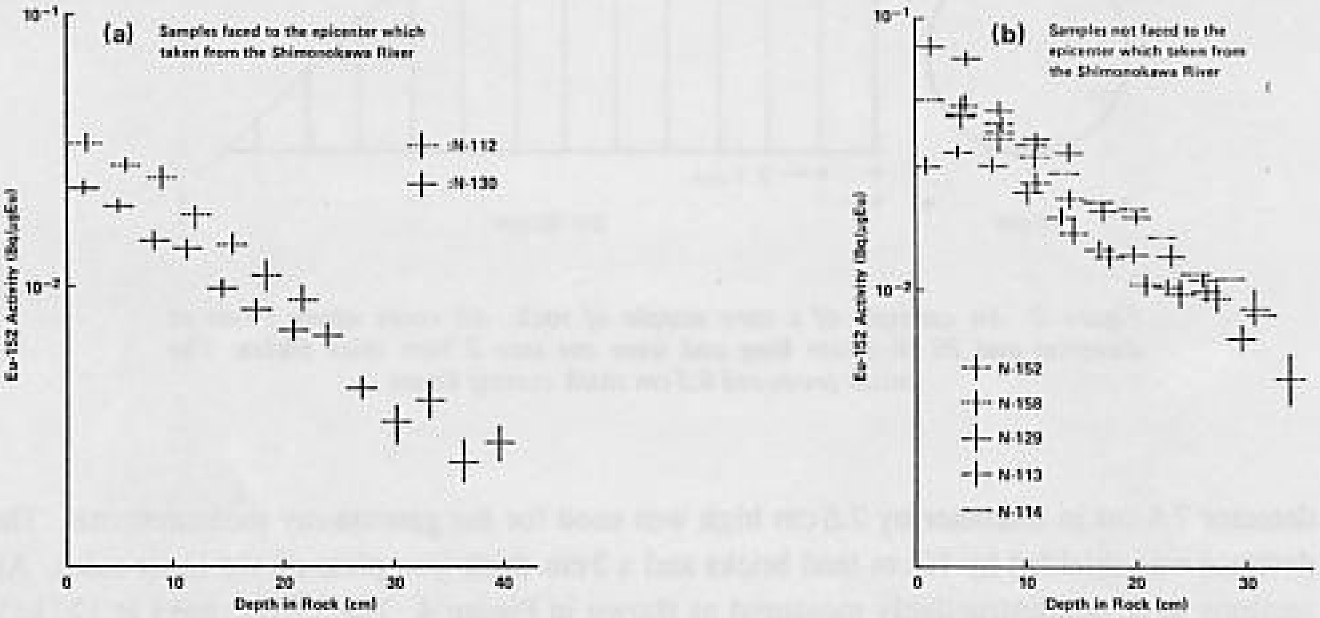
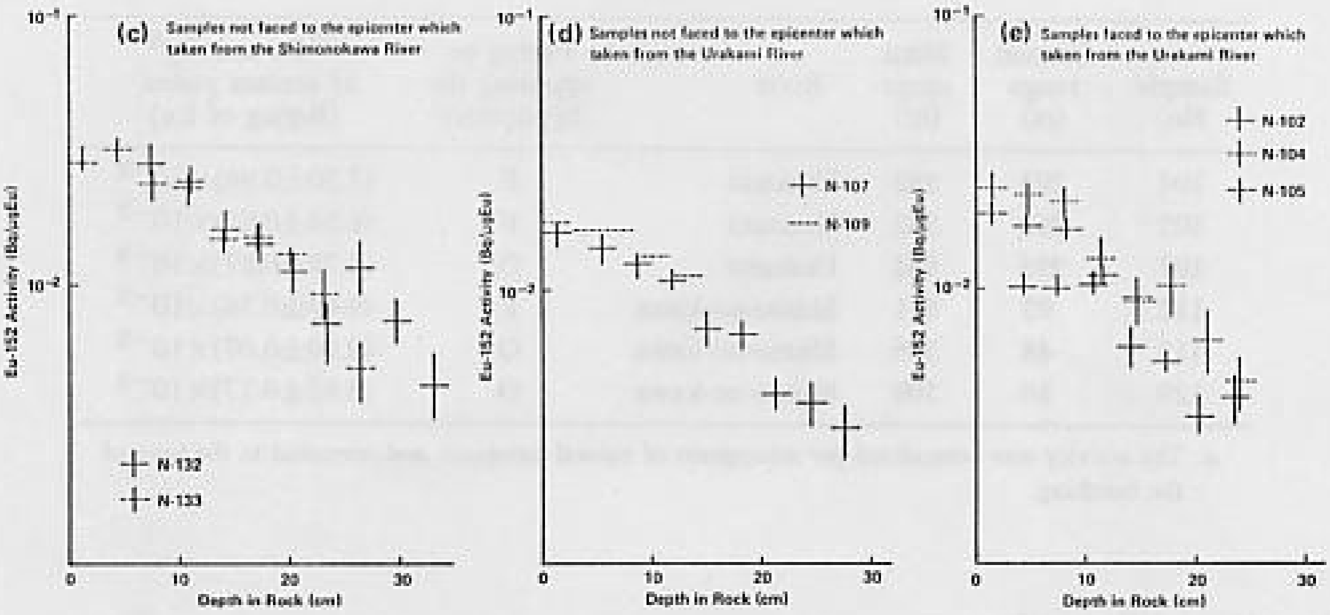


Figure 5. Depth distribution of ^{152}Eu activity in rock. The activity was normalized per microgram of natural europium and corrected to the time of bombing.

Figure 5 (Continued)



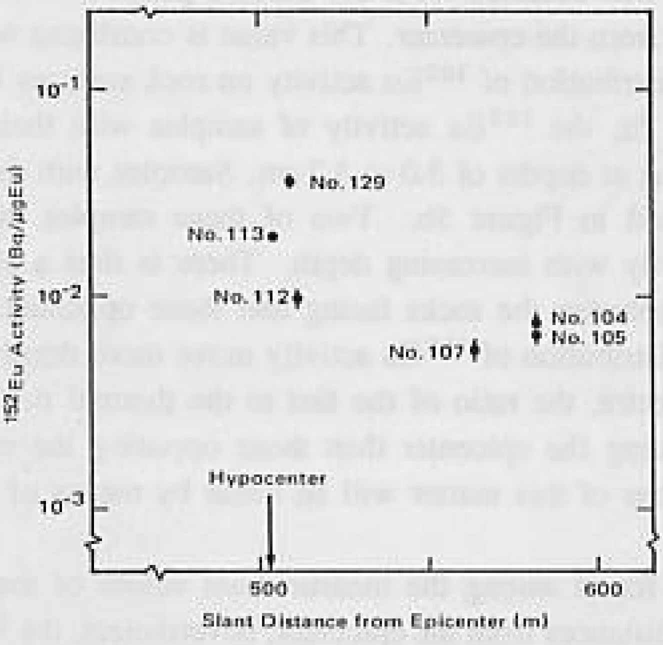


Figure 6. 152Eu activity of the surface plates plotted against the slant range

same volume of rock powder with standard ^{152}Eu activity kept in the same container. Thus, the detection efficiency of ^{152}Eu for the plates was obtained.

The other sections were measured as plates and their measured values were evaluated by using the detection efficiency. To determine the amount of natural europium contained in each rock sample, activation analysis was performed at the Research Reactor of Kyoto University (KUR).[1]

Table 1. The Activity of ^{152}Eu in Core Samples Taken from Near the Hypocenter in Nagasaki

Sample No.	Ground range (m)	Slant range (m)	River	Facing or opposing the hypocenter	^{152}Eu activity[a] of surface plates (Bq/μg of Eu)
104	293	582	Urakami	F	$(7.50\pm0.96)\times10^{-3}$
105	293	582	Urakami	F	$(6.84\pm0.67)\times10^{-3}$
107	255	564	Urakami	O	$(5.78\pm0.67)\times10^{-3}$
112	93	511	Shimo-no-kawa	F	$(9.69\pm0.58)\times10^{-3}$
113	48	505	Shimo-no-kawa	O	$(2.00\pm0.07)\times10^{-2}$
129	80	509	Shimo-no-kawa	O	$(3.62\pm0.17)\times10^{-2}$

[a] The activity was normalized per microgram of natural europium and corrected to the time of the bombing.

Results and Discussion

The average values of residual activity of ^{152}Eu in each 2.7 cm thick section were obtained by gamma-ray measurements. The measured values were normalized per microgram of natural europium and converted to activity at the time of bombing. Figure 5 shows the depth distribution of ^{152}Eu activity in the rocks. The highest value of 3.6×10^{-2} Bq per μg of natural europium was obtained from the surface plates of sample No. 129, which had been taken at 509 m from the epicenter. This value is consistent with results previously reported on the spatial distribution of ^{152}Eu activity on rock surfaces in Nagasaki.[1]

As shown in Figure 5a, the ^{152}Eu activity of samples with their surfaces facing the epicenter has a peak value at depths of 3.0 to 5.7 cm. Samples with their surfaces opposing the hypocenter are plotted in Figure 5b. Two of these samples demonstrate monotone reduction in ^{152}Eu activity with increasing depth. There is thus a clear difference in the neutron energy spectra between the rocks facing and those opposing the epicenter. Since the peaks of the depth distribution of ^{152}Eu activity move more deeply inward with energy hardening of neutron spectra, the ratio of the fast to the thermal neutrons is larger on the surfaces of the rocks facing the epicenter than those opposing the epicenter. In a future study further investigations of this matter will be made by means of an unfolding method for energy spectra.

A wide deviation is found among the measurement values of the surface plates when plotted against the slant distances from the epicenter; nevertheless, the ^{152}Eu activity tends to decrease with increasing slant distance, as shown in Figure 6. These results are summarized in Table 1.

Reference

1. Okajima, S. and Miyajima, J., 1983. Measurement of neutron-induced ^{152}Eu radioactivity in Nagasaki. In *U.S.-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki*, pp. 156-168. Hiroshima: Radiation Effects Research Foundation.