Chapter 8

ACTIVATION MEASUREMENTS FOR THERMAL NEUTRONS

Part C. ^{152}Eu Depth Profile Measurements in Japan

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Introduction

The neutron energy spectrum from the atomic bomb consisted of a range of energies from thermal to fast neutrons. Fast neutrons contribute a larger dose to the human body than low-energy neutrons per unit flux. The evaluation of the fast neutron component has been performed based on analyses of ^{32}P (>3 MeV) activity measured immediately after the Hiroshima bomb and ^{63}Ni (>2 MeV), which has a much longer half-life (100 y) and which was measured by the AMS method.

An indirect way to investigate 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 by scattering among the granite elements until they become slow or thermal neutrons. Then the neutrons induce ^{152}Eu activity through neutron capture reactions along their paths in the rock. The resulting activity as a function of depth reflects the energy spectrum of incidence neutrons.

The ^{152}Eu depth profiles were measured for granite and concrete cores within 500 m of the hypocenter in Hiroshima. They were Motoyasu Bridge granite pillar (Hasai et al. 1987), other granite pillars of Motoyasu Bridge and Shirakami Shrine, and concrete cores of Hiroshima Bank and Gokoku Shrine (Shizuma et al. 1997). The results were compared with calculation.

Materials and Methods

Motoyasu Bridge Pillar-1 (MP1)

Among 8 pillars of the Motoyasu Bridge, a pillar (MP1) was located 128 m from the hypocenter. Four granite cores were bored in the pillar: two horizontal cores (6.8 cm diameter

and 82 cm long) along a north-to-south axis (core #1) and west-to-east axis (core #2), a vertical core from the top of the pillar (#3) and a concentric core (core #4) of 12.7 cm diameter in the same location as core #1 for the purpose of elemental analysis and other measurement. The height of core #1 from the river water surface was 477 ± 8 cm, at the same tide level as when the atomic bomb was detonated. The core samples were cut into disks with an average thickness 1.8 cm. Each disk was measured directly by a low-background Ge detector. The Ge detector was a coaxial type (124 cm^3 volume) with a relative efficiency 28%. The ^{152}Eu radioactivity in the surface sample was performed separately.

Motoyasu Bridge Pillar-2 (MP2)

Another granite core was bored in a different pillar of Motoyasu Bridge. The pillar-2 was located 93 m from the hypocenter and standing just on the bank of the river. A core of 5.5-cm diameter and 71-cm long core was extracted at 43 cm height from the ground level in an east-west direction.

Shirakami Shrine Core (SS core)

Shirakami Shrine is located 487 m from the hypocenter in the south-southeast direction. At this location, a 6.8-cm diameter and 82-cm long vertical core was bored in the center of a large granite rock with a surface size of 2 m × 3.1 m. A concentric core of 12.7 cm diameter was also bored in the center of the SS core for analysis of chemical components.

Gokoku Shrine Core (GS core)

Gokoku Shrine is located 388 m north of the hypocenter. A large concrete foundation (90 cm × 110 cm × 145 cm) existed in the northern gate of the shrine. A 6.8-cm diameter and 42-cm long vertical core was bored from the surface of the foundation.

Hiroshima Bank Core (HB core)

Hiroshima Bank (formerly Geibi Bank) is located 257 m east of the hypocenter. A 6.8 cm diameter and 250-cm long horizontal core was bored from a pillar-top decoration of the building. The height of the core position is assumed to be 17 m from the ground level.

Measurement Procedure

Cores of MP2, SS, GS and HB were cut into 1.8-cm-thick disks for gamma-ray measurements. Although the ^{152}Eu gamma-ray peaks were detected for all the MP2 core disks, it was difficult to detect the gamma-ray peaks at depths over 10 cm for SS, GS and HB cores. Thus, chemical separation was performed to measure ^{152}Eu activity up to about 40 cm in depth. A well-type Ge detector was utilized for this measurement.

It is necessary to determine the Eu concentration in each disk sample, however, the concentration was assumed to be uniform in each core. In the case of MP1 core, the Eu concentration was obtained by activation analysis for several samples. The Eu concentration ranged 0.85 to 1.05 $\mu g\ g^{-1}$, and the uncertainty of the uniformity of stable Eu in the core was estimated to be 6%.

The water content of the granite was extensively investigated for the MP1 core. Details are described in the reference (Hasai et al. 1987).

Results

The depth profiles of the cores #1 to #3 and of MP1 are shown in Figure 1. The intensity of ^{152}Eu was nearly the same for the four surfaces of the pillar (cores #1 and 2), but decreased to about 1/3.5 of the surface intensity at the centroid of the pillar (core #1).

The depth profile of MP2 is compared to that of MP1 (core #1) in Figure 2. The two profiles agree well with each other. Depth profiles of the granite core SS and the concrete cores are shown in Figure 3.

The relaxation length (L) was estimated from the depth profiles of MP1, SS and GS cores. They were 13.6 cm (MP1), 12.2 cm (SS) and 9.6 cm (GS). The relaxation length is almost the same for MP1 and SS cores, but that of the concrete GS core as well as the HB core is somewhat smaller.

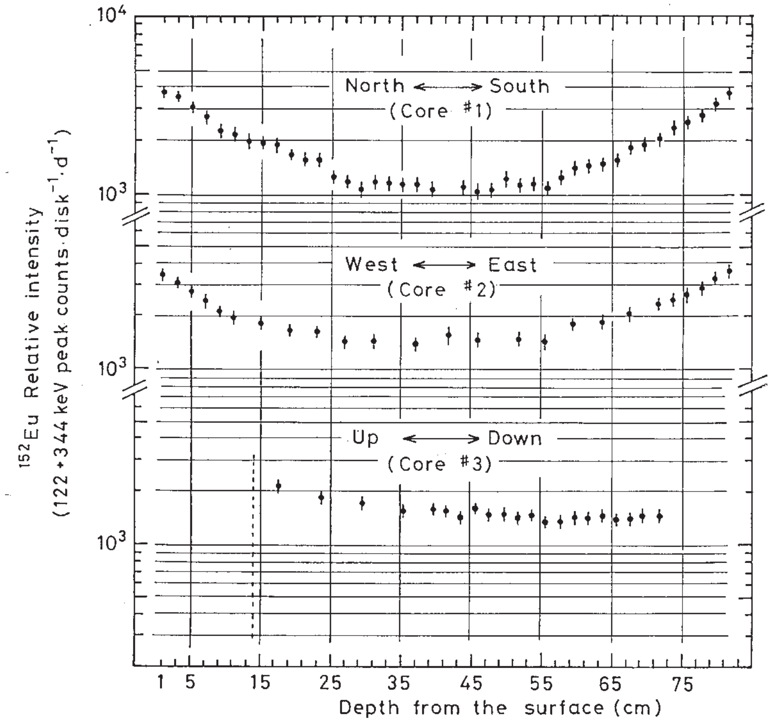

Figure 1. *Depth profiles of ^{152}Eu in the granite pillar (MP1) of the Motoyasu Bridge. (Hasai et al. Health Phys. 53: 227-239; 1987)*

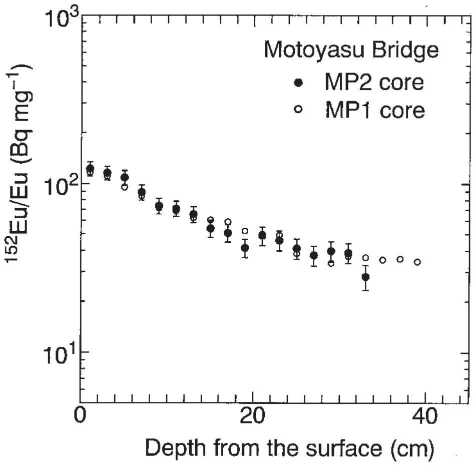

Figure 2. *Comparison of depth profiles of ^{152}Eu in granite cores of the Motoyasu Bridge. (Shizuma et al. Health Phys. 72: 848-855; 1997)*

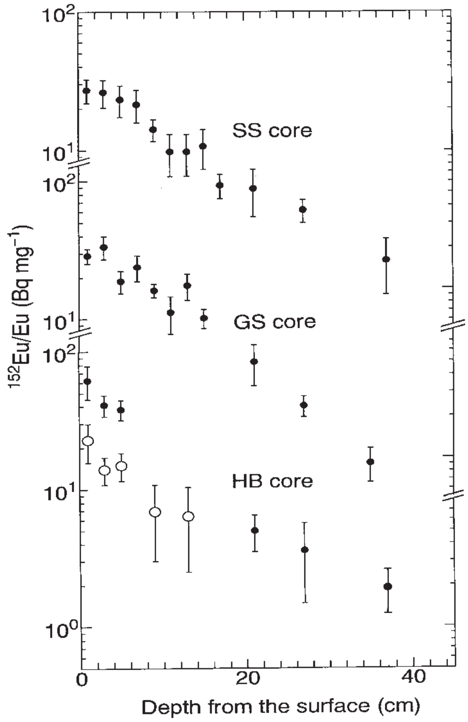

Figure 3. *Depth profiles of ^{152}Eu in the granite core of Shirakami Shrine (SS) and concrete cores Gokoku Shrine (GS) and Hiroshima Bank (HB). Open circles of the HB core indicate the depth profile measured from near the surface of the core. (Shizuma et al. Health Phys. 72: 848-855; 1997)*

Calculations

The depth profile of ^{152}Eu was calculated for the granite cores of MP1#1 and SS, simulating the structure of the sample places with three dimensional Monte Carlo codes: MORSE and MCNP (Endo et al. 1999). The DS02 neutron source for Little Boy was used as a point source at 600 m above the hypocenter. The results are shown in Figures 4 and 5 for MP1#1 and SS, respectively.

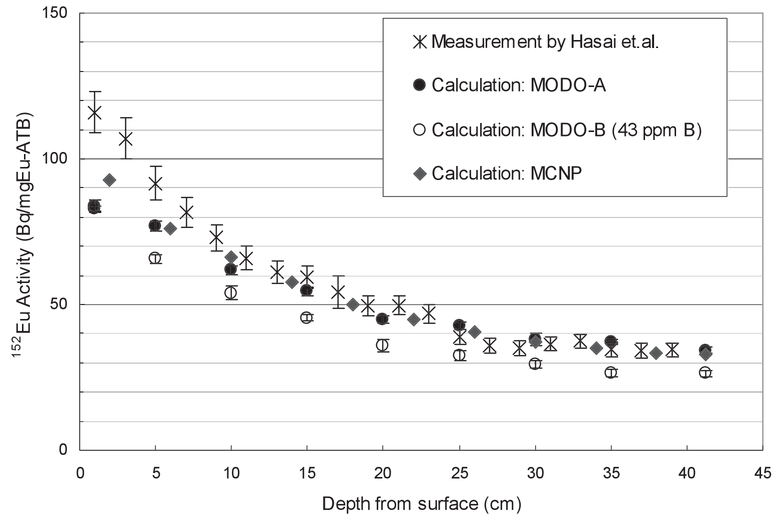

Figure 4. *^{152}Eu depth profile in granite core of Motoyasu Bridge (MP1#1): calculations and measurements.*

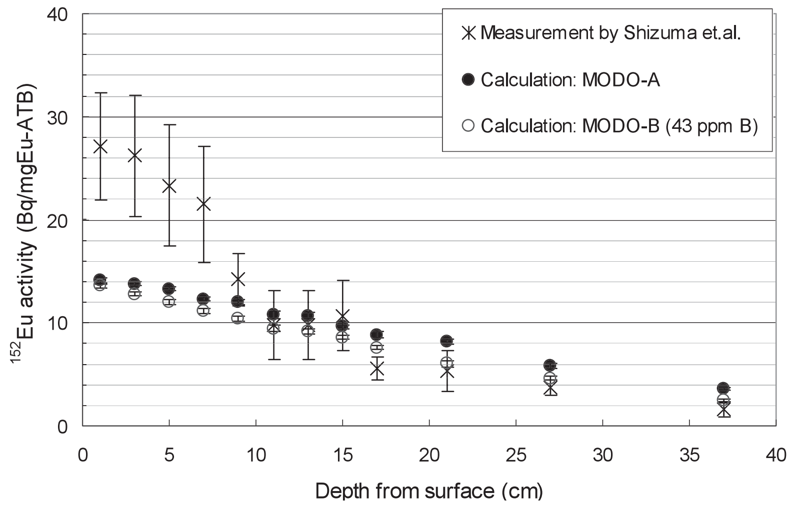

Figure 5. *^{152}Eu depth profile in the granite core of Shirakami Shrine (SS): calculations and measurements.*

In Figure 4 the results of three calculations are shown together with the measurement. The first two calculations (MODO-A and -B) were obtained by an interface code, MODO, which can couple the results of forward-DOT3.5 and adjoint-MORSE at a cylindrical surface around the sample structure. The third calculation is a two-step (forward-forward) MCNP calculation, in which the result of the first-step calculation was used to compile a surface source around the sample structure for the second-step calculation. The same composition of MP1 granite was used in the three calculations, except that MODO-B contained 43 ppm of boron, which represented thermal capture effects of four trace elements: B, Sm, Gd and Li.

The results of MODO-A and MCNP show good agreement with the measured data at depths deeper than 15 cm, although the calculated values are somewhat lower than the measurements at shallow depths. (Note: The MCNP calculations did not include delayed neutrons, which are about 10% of activation.) The boron addition did not change the calculated value at 1 cm, but it became gradually more effective with depth. It reduced the ^{152}Eu activity by about 25% at depths of 30-40 cm. In the case of the calculation for MP1, the addition of 43 ppm boron made the agreement between calculation and measurement a little bit worse.

The result of the ^{152}Eu depth profile calculation for the SS core is shown in Figure 5. The calculated values are considerably lower than the measurements at depths less than 7 cm. However, such disagreement is not observed at depths greater than 10 cm. The addition of 43 ppm boron reduced the calculated ^{152}Eu activity in the same way as for MP1. In contrast to MP1, the boron addition to SS granite made the agreement between calculation and measurement a little better.

The discrepancy observed in the surface regions for both the MP1 and SS cores should be investigated in more detail. Measurement of trace elements in granite cores should be done to clarify the effect of such elements.

Conclusions

Depth profiles of ^{152}Eu activity induced in granite or concrete by neutrons released from Hiroshima atomic bomb were measured for 5 samples (3 granite and 2 concrete) located within 500 m of the hypocenter. The relaxation lengths for ^{152}Eu depth profiles in granite cores were larger than those in concrete cores.

The ^{152}Eu activity in granite cores was also obtained by calculations using the DS02 neutron spectrum for Little Boy bomb used in Hiroshima. Comparison of calculated profiles with measured ones indicates that the agreement between calculations and measurements is not satisfactory in the surface layers (<10 cm) of the cores, although it becomes better in deeper layers (>10 cm).

Additional calculations and chemical analyses, including trace elements such as B, Sm, Gd and Li in the individual measured samples, are necessary for further evaluation of depth profiles of ^{152}Eu activity induced by atomic-bomb neutrons.

References

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