I. DOSIMETRY

C. Dose Estimation from Residual and Fallout Radioactivity

2. A Simulated Neutron Activation Experiment

HASHIZUME, T. and MARUYAMA, T.

Division of Physics, National Institute of Radiological Sciences, Chiba, 280, Japan
(Received April 9, 1975)

Soil and various building materials from Hiroshima and Nagasaki were irradiated with neutrons and their induced radioactivities were determined. Based on these measurements, the dose rates and cumulative doses from the induced gamma-emitters in Hiroshima and Nagasaki were estimated. The cumulative dose to infinity at the hypocenter was 80 rads in Hiroshima and 30 rads in Nagasaki.

INTRODUCTION

The radiation doses from residual radioactivity on the bombarded areas have been estimated from areal surveys of radioactivity (see the preceding review by Takeshita). Another approach is by simulated neutron activation experiments. In early 1960s, Shono and Arakawa estimated gamma rays from the residual radioactivity with the use of some neutron activation experiments of soil from Hiroshima and Nagasaki. However, their results varied a great deal depending also upon the methods of calculation. With recent advances in quantitative dosimetry and in gamma ray spectroscopy, the authors re-estimated the external radiation doses due to gamma-rays by simulated neutron activation experiments of soil and building materials.

NEUTRON ACTIVATION EXPERIMENTS

Soil, roof-tiles, bricks, asphalt, wood and concrete blocks were collected from Hiroshima and Nagasaki. They were powdered and exposed either to thermal neutrons from a reactor (Hitachi Training Reactor, Tokaimura, Japan) or to fast neutrons from the $^9$Be $(d, n)^{10}$B reaction with a Van de Graaff generator. The induced radioactivities were mostly from the $(n, \gamma)$ reaction by thermal neutrons and to a negligibly small extent from the $(n, p)$ and $(n, \gamma)$ reactions by fast neutrons.

Dominant species of induced radioactivities were determined from the gamma-ray spectra in a well type NaI (TI) crystal (Figure 1). Within one hour after irradiation, they were $^{28}$Al (2.3 minutes), $^{24}$Na (15 hours) and $^{56}$Mn (2.58 hours). Those after 10 days were $^{46}$Sc (84.1 days) and $^{60}$Co (5.24 years) with a small amount of $^{140}$La (40.3 hours). Later $^{134}$Cs (2.1 years) became apparent as $^{46}$Sc disappeared. Preliminary radiochemical analysis of soil activated by neutrons showed that soil contained small amounts of $^{59}$Fe, $^{65}$Zn and $^{42}$K. These nuclides were masked by $^{24}$Na, $^{46}$Sc and $^{60}$Co on the gamma-ray spectra.

* 橋詰 雅, 丸山隆司: 放射線医学総合研究所, 千葉市浦安 4-9-1 〒280
From these studies, the major gamma-emitters, considered for gamma-ray dose estimation, are five: $^{56}$Mn, $^{24}$Na, $^{44}$Sc, $^{60}$Co and $^{134}$Cs.

**THE DOSE ESTIMATION AT 1 m ABOVE GROUND**

The doses from soil and building materials were calculated at 1 m above the ground in an infinitely extended field on the basis of the following assumptions together with some experiments.

1. Five nuclides are distributed uniformly in soil and building materials.
2. Thermal neutron fluences on the ground surface can be determined from the specific activity of $^{60}$Co in iron materials on the surface of existing ferro-concrete buildings in Hiroshima and Naga-saki.
3. As fast neutrons are converted into thermal neutrons within a medium, they also induce the activation of soil and building materials.
4. The specific activity induced in soil and building materials per unit fast neutron dose can be determined experimentally using neutrons from the $^9$Be(d,n)$^{10}$B reaction as a simulated source for atomic bomb neutrons.
5. The attenuations of gamma-rays in soil and air can be determined using $^{24}$Na, $^{60}$Co and $^{137}$Cs gamma-ray sources which were placed at various depths in soil in an open field.

The exposure rates from the five radionuclides induced in soil immediately after the explosion were calculated at the hypocenter, 500 m and 1000 m from the hypocenter in Hiroshima. Also, the exposure rate from roof-tiles was calculated, assuming that they were irradiated in a state as they were used in buildings, and were scattered by the blast and spread uniformly 1.4 cm thick (roof-tile thickness) over the ground surface. These resultant exposure rates were given in Table 1. As a value for conversion factor from exposure (R) to absorbed dose (rad), 0.96 was used for the whole gamma-rays from

<table>
<thead>
<tr>
<th>Table 1. The dose rate* due to neutron-induced radioactivities in soil and roof-tiles immediately after the explosion of the atomic bombs in Hiroshima.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from hypocenter (m)</td>
</tr>
<tr>
<td>Soil</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Roof tiles</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

* In-air tissue absorbed dose rate (rad/hour) can be estimated by multiplying dose rate (R/hour) by 0.96.
the five nuclides.

A person entering the hypocenter the day after the Hiroshima explosion and working there for 8 hours would have received a dose of 3 rads from activated soil. The cumulated dose from soil activated at the hypocenter in Hiroshima from immediately after the explosion to infinite time was estimated to be 80 rads. At 500 m and 1000 m from the hypocenter, the cumulated doses to infinity would be about 18% and 0.07% of that of the hypocenter. Similar estimations were also made for Nagasaki. However, since the neutron dose at Nagasaki was one third of that of Hiroshima and $^{55}\text{Mn}$ content of Nagasaki soil was about twice of that of Hiroshima, the cumulated dose at the hypocenter to infinity was estimated to be about 30 rads.

It is stated that the present estimations were made principally on the dose from radioactivities induced in soil. With the above mentioned conditions, the estimates were subject to some variations depending on the following circumstances: (1) $^{23}$Na and $^{55}$Mn content in soil varied up to 1.5 times more than the average value in some sites. Thus the present estimates may vary by as much as a factor of 1.5. (2) Since the specific activities of bricks, concrete and asphalt were as large as those of soil and roof-tiles, the present estimates made only from soil were subject to some variation, if these materials became major sources of radiations. (3) Ashes from wooden houses were rich in $^{24}$Na and $^{48}$Mn and would give 0.58 R/hr at the hypocenter immediately after the explosion, assuming that the average quantity of wood used for constructing a house was 50 kg/m$^2$ and that wood was equally activated by atomic bomb neutrons. The people who entered the burnt down areas of wooden houses would be exposed to the doses from ashes and/or roof-tiles other than those from soil. (4) As Mather$^5$ pointed out, thermal neutron fluence in soil would be greatly affected by its water content. Since the moisture content of soil was not known at the time of explosions, water content (average 30%) estimated at the time of soil collection in Hiroshima (summer of 1966) were used. (5) The present dose estimation did not consider a contribution of beta-irradiation, nor contribution of fallout of fission products, nor internal doses from inhaled and ingested radioactivities by persons. (6) No correction was made for shielding of buildings and others against the atomic bomb neutrons and the gamma-rays from their induced radioactivities.

However if the course and behaviour of early entrants in Hiroshima and Nagasaki were known, some reasonable estimation of doses from induced radioactivities could be made by the use of present estimates.

REFERENCES