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Measurements and Calculations of Beta Dose Rates on the Contaminated Ground at the Fukushima Daiichi Nuclear Power Plant Site

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Introduction

The accident at the Fukushima Daiichi Nuclear Power Plant resulted in a substantial release of fission and activation products into the environment, creating a harsh radiation field of gamma and beta rays. Hundreds of emergency workers were devoted to an attempt to keep the situation under control. In the course of the initial plant stabilization operations, a few tens of the workers received external gamma exposures exceeding 100 mSv; however, there were no records on the beta exposures.

The objectives of the present study are:
(1) to reconstruct the gamma and beta mixed radiation fields in outdoor environments at the site by use of computational dosimetry techniques, and
(2) to provide data applicable to assess the worker's beta exposures.

Measurements

Soil samples were collected on 21-22 March 2011 at several locations within 0.5-1 km from the reactor Units 1 and 2 for:
- HPGe spectroscopy and radiochemical analysis
- measurement of gamma and beta dose rates at the surface of the soil samples

Table 1 Major radionuclides found in soil samples and their concentrations

Soil sample [a]	Sampling date	Density (g/cm³)	Concentration [b] (Bq/cm³) ^{129m}Te	^{132}Te	^{131}I	^{134}Cs	^{137}Cs	^{131}I/^{137}Cs
North	21/03/11	1.6	1.4E+3	3.0E+3	5.0E+3	1.5E+3	1.6E+3	3.1 (8 [c])
West	21/03/11	1.4	3.3E+2	7.9E+2	7.5E+3	4.4E+2	4.4E+2	17 (40)
South	21/03/11	0.8	7.6E+0	1.7E+1	6.3E+2	7.0E+0	1.6E+1	40 (100)

[a] Soil samples from north, west and south of the reactor buildings were collected from the ground near a solid waste storage facility (500-m north of the stack of Unit 1), an athletic field (500-m west-northwest), and a storage yard (500-m south-southwest), respectively.
[b] Top soil to a depth of 5 cm was assumed to be collected; therefore, the deposition density (Bq/cm²) used for Monte-Carlo calculations was estimated by multiplying the concentration by 5 cm.
[c] Ratios in parenthesis were decay-corrected to 12 March, i.e., the day of the initial PCV venting at Unit 1.

Calculations

Code: MCNP-4C3
Geometry: Air-ground interface
Soil: 200 mϕ × 30 cm, 1.6 g/cm³
Air: 200 mϕ × 200 m, 1.2mg/cm³
Source term:
^{106}Rh, ^{129m}Te, ^{132}Te-^{131}I, ^{131}I, ^{133}I, ^{134}Cs, ^{136}Cs, ^{137}Cs-^{137m}Ba, ^{140}Ba-^{140}La
Beta source spectra:
ICRU Report 56, BETABREM code
Source radius:
20m for β, 100m for γ
Source depth: 0.1 mm and 1 mm
Tally:
- Spectral current and fluence (F1&F2) with both cosine multiplier and segment cards
- Folded with conversion coefficients of $H'(0.07)/\phi$ for β, and $H^*(10)/\phi$ and $H_p(10)/\phi$ for γ.

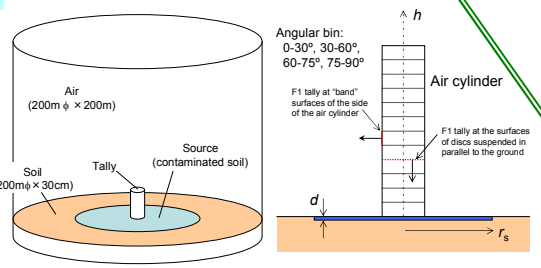
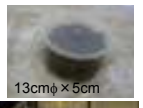


Fig. 2 MCNP calculation geometry, showing (a) the whole view of the air-ground interface, and (b) the tallies used in the calculations. Arrows shown in (b) represent the reference orientations of the F1 tallies, and particles coming from the opposite side are disregarded in the calculation of both $H_p(0.07)$ and $H_p(10)$. The source radii of *r*s are 20 m for beta sources and 100 m for gamma sources, with the source depths of d= 0.1mm and 1 mm.



Oyo-giken Model AE-133B air ionization chamber

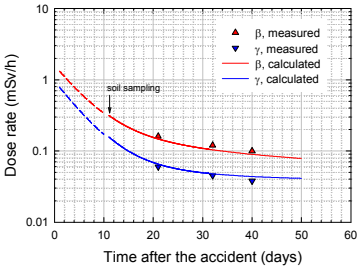


Fig. 1 Measured and calculated gamma and beta dose rates 5 cm above the surface of the north soil sample plotted against the number of days after the accident Dashed lines were extrapolated by simple decay corrections.

Results

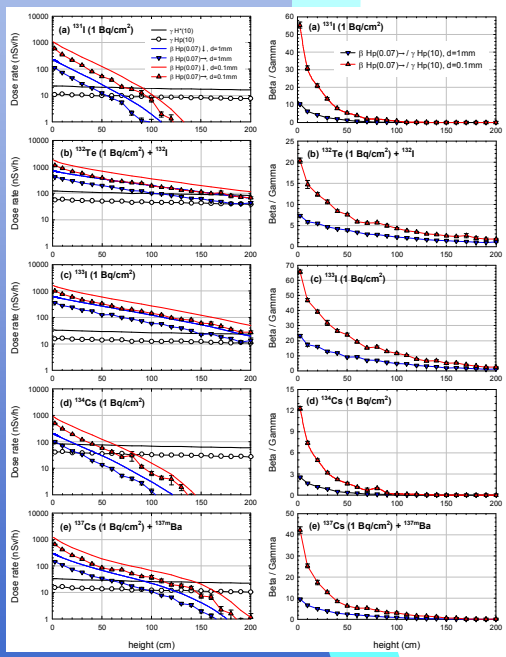


Fig. 3 Variation in beta and gamma dose rates (left) and in beta-to-gamma dose ratios (right) with height above the ground for major dose contributors of (a) ^{131}I, (b) ^{132}Te-^{132}I, (c) ^{133}I, (d) ^{134}Cs, and (e) ^{137}Cs-^{137m}Ba. Arrows (↓ , →) in the caption represent the reference orientation of the F1 tally in the space to calculate angular-dependent $H_p(0.07)$ and $H_p(10)$.

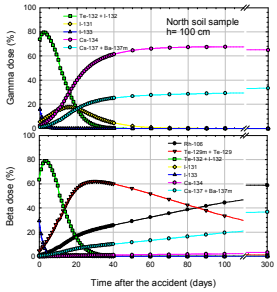
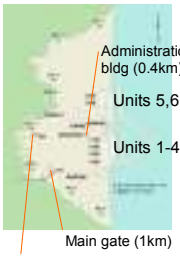


Fig. 4 Relative dose contribution at 1m above the ground (north soil sample)



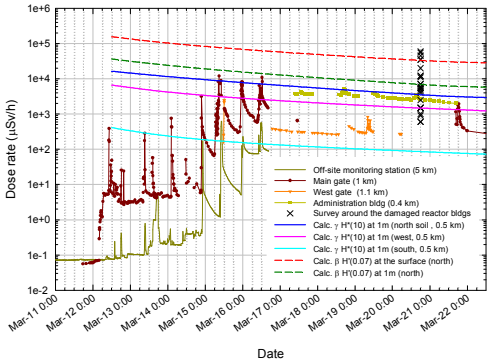


Fig. 5 Early time course of dose equivalent rates on-site and off-site. Plotted are the readings of an off-site monitoring station (5 km), on-site temporary stationary monitors (0.4-1.1 km), and survey instruments around the damaged reactor buildings. The calculated gamma and beta dose rates, based on the soil samples (0.5 km), are also presented in bold solid and dashed lines, respectively.

Beta Exposures to the Workers

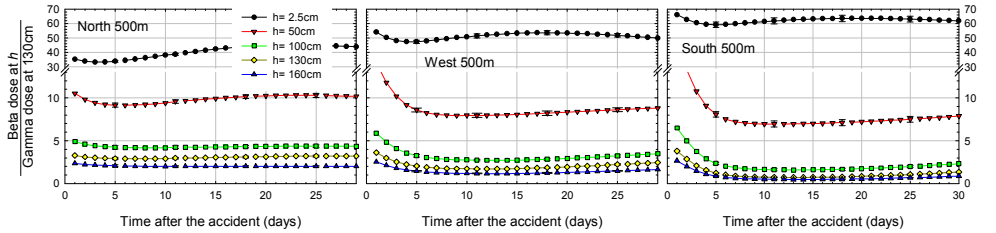


Fig. 6 Ratios of the beta doses at various heights (h) to the gamma dose at 130 cm above the ground for the deposition of 0.1 mm.

Workers' maximum possible **gamma** dose (outdoors): ~100 mSv at chest level
×
Beta-to-gamma dose ratio ~10 at knee level ~3 at chest level
=
Estimated maximum **beta** dose to **unprotected skin** (outdoors): ~1 Sv at knee level ~0.3 Sv at chest level

The estimated maximum beta exposures were unlikely to exceed the dose limit of 1 Sv, with the expectation of further reduction by the ground surface roughness (by up to a factor of ~3) and the protective clothes (by ~2).