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ARTICLE

Study on restricted use of contaminated rubble on Fukushima Daiichi NPS site (2) Validation of reference radiocesium concentration for recycling materials

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Tokyo Electric Power Company has been planning that a part of rubbles arising from the accident of the Fukushima Daiichi NPS (1F) will be recycled and applied in a restricted reuse only within 1F site. For ensuring the safety of the restricted reuse, we have been developing a new methodology for evaluation of reference concentration for the restricted reuse, considering current situation of radiation control at the 1F site. In this study, in order to validate the reference radiocesium concentrations of recycling material used for the road (1.0×10^5 Bq/kg) and the base of a concrete building (1.6×10^5 Bq/kg), which have been calculated for the restricted reuse of contaminated rubbles, we evaluated (1) additional occupational dose, (2) annual dose at the site boundary, (3) radiocesium concentration in groundwater at the outlet to the ocean. (1), (2) and (3) are should be below 2 mSv/y, 1 mSv/y and 1 Bq/L, respectively. As a result, additional occupational dose was calculated as 1.3 mSv/y. Annual dose at the boundary was 1 mSv/y with condition of more than the distance of 25 m from the road. Calculated radiocesium of ^{134}Cs and ^{137}Cs concentrations in the groundwater at the outlet to the ocean were the below the 1 Bq/L with condition of distance of more than 5 m from the building. The calculated reference radiocesium concentrations were validated for the restricted reuse within the 1F site.

Keywords: ***Fukushima Daiichi NPS; restricted reuse; recycling materials; contaminated rubble; radiocesium; reference concentration; dose estimation; radionuclides migration***

1. Introduction

A large amount of contaminated rubbles arising from the accident and the activities toward the decommissioning is stored in the Fukushima Daiichi NPS (1F) site. Of the rubbles with less than 1 mSv/h of surface dose rate stored outdoor in the site, rubbles with less than 5 μSv/h will be recycled and applied in a restricted reuse only within the 1F site in the future [1]. However, there is no precedent for establishing the reference values such as dose and/or concentration for reuse or recycling under the existing exposure situation. In order to appropriately introduce the restricted reuse in the 1F site, technical and regulatory studies are necessary.

We suggested a methodology for establishing the reference radioactive concentration consisting of ^{134}Cs and ^{137}Cs in recycling material for the restricted reuse in the 1F site under existing exposure situation, and for validating for restricted reuse at the 1F site. Then we calculated the reference radiocesium concentrations of the recycling material used for paved roads and the bases of concrete building [2]. The reference concentrations are calculated so that increased dose rate by restricted reuse does not exceed 1 μSv/h. When the recycling material under the reference concentration is reused in actual operation situation of the 1F, validation for the reference concentration is indispensable to confirm that the impact on worker in the 1F site and public by recycling material is small significantly.

Therefore, we studied the evaluation methodology for validation of the reference concentrations of recycling material used for the road and the base of a concrete building, taking into account the current situation of the management of radiation protection for workers and public in the 1F site. And then, we calculated the additional worker doses, annual dose at the boundary of the 1F site and radionuclide concentrations in the groundwater at the outlet to the ocean.

2. Evaluation methodology for validation of calculated reference concentrations

We suggested that the reference concentrations should be validated by confirming following three items to satisfy with the criteria, (1) additional annual dose for workers, (2) impact to air dose rate at the site boundary, (3) impact of radionuclides migrating to the ocean. **Figure 1** shows the methodology for evaluation of

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reference concentration and validation for restricted reuse. Reference concentrations are validated based on the actual situation in restricted reuse for paved road and base of building in the 1F site. In the item (2) and (3), available conditions for restricted reuse such as distance from site boundary are suggested.

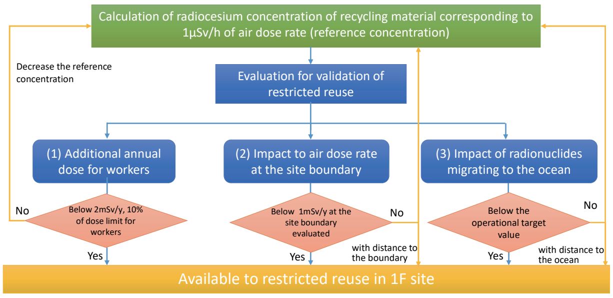

Figure 1. Methodology for evaluation of reference concentration and validation for restricted reuse at the 1F site.

2.1. Additional annual dose for workers

Exposure doses of workers in the 1F site will increase by use of recycling materials. It is necessary to confirm that the additional exposure doses are below 2 mSv/y to ensure the working time for the decommissioning activities. In this validation, worker doses are evaluated for workers who probably receive high additional exposure doses from recycling material in decommissioning activities in the 1F site.

For the reuse as the road material, additional doses are estimated for four cases determined by combination of paved type (asphalt or concrete) and applied place (roadbed or pavement). Workers at a side of the road and drivers on the road, which may be the closest to the road as a radiation source, were selected as the evaluation target (**Figure 2**). In reusing for pavement, we evaluate not only the external exposure but also internal exposure by dust inhalation, considering generation and dispersion of radioactive dust from pavement surface.

When the recycling material is used for the base of building, a worker at the center of the bottom floor is selected as the evaluation target (**Figure 3**). Internal exposure is neglected for the evaluation of the base, because the contaminated base is covered by floor slab consisting of no-contaminated material.

In both cases, annual working time is 1,430 h/y assuming five working days in a week by 5.5 h/d work

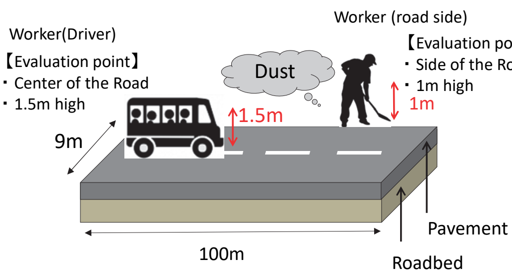

Figure 2. Geometry for additional annual dose for workers near road.

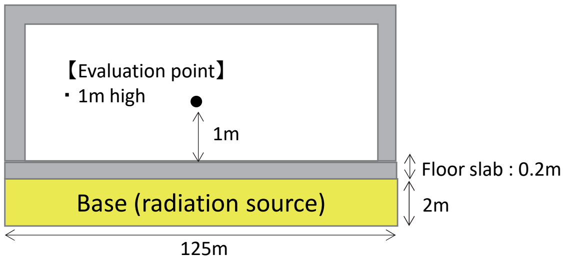

Figure 3. Geometry for additional dose for worker in building.

time. Dose conversion coefficients for external exposure dose are calculated by MCNP5 [3]. MCNP5 has been used in many evaluations of dose rate by direct radiation and skyshine radiation far from radiation source [4].

2.2. Impact to air dose rate at the site boundary

Air dose rate in the 1F site will increase by restricted reuse of recycling materials. Annual doses at boundary of the 1F site are affected by not only recycling material but also gaseous, liquid and solid wastes originated from 1F site. It is necessary to confirm that the annual doses at the site boundary are less than 1 mSv/y, which is the evaluation target at site boundary. **Figure 4** shows the annual doses at a hundred points along the site boundary. The annual doses are reported in March, 2017 [5]. The annual doses are below 1 mSv/y at all of evaluation points and less than 0.6 mSv/y in many evaluation points. Therefore, in order to satisfy the 1 mSv/y at the site boundary, air dose rate from recycling material under the reference concentration should be less than 0.4 mSv/y at the site boundary. In this validation, we evaluate the distance from the position of reuse to the boundary not to exceed the 0.4 mSv/y.

Figure 5 shows evaluation geometry of road for air dose rate evaluation. Road geometry for the evaluation is set based on present road constructed situation in the 1F site. According to aerial photograph in the 1F site, roads occupy about 10 % of a 500 m×500 m area. Then road area is set to 20 % of the 500 m×500 m area assuming that additional roads will be constructed for decommissioning activities in the future. In evaluation geometry, accumulating multiple roads into one area (length:500 m, width:100 m), the area is assumed to be located at the boundary side conservatively. Reference concentration for the asphalt pavement is used for this validation as representative reference concentration. Air dose rate is calculated by the distance from the road. Dose conversion coefficients for external exposure are calculated by MCNP5 [3]. In this calculations. direct radiation and skyshine should be considered as additional air dose rate from recycling material. MCNP5 has been used for site boundary dose rate evaluation taking direct radiation and skyshine into account in the 1F.

On the other hand, the geometry of the concrete building with base for evaluation is set based on the 9th solid waste storehouse in the 1F site [5].

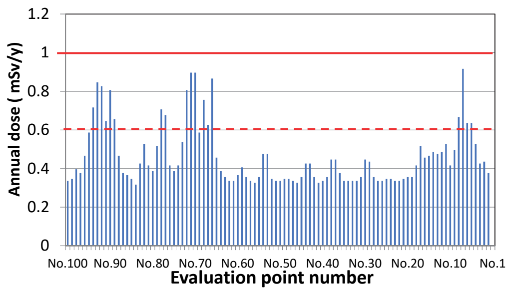

Figure 4. Annual dose at the site boundary evaluation points.

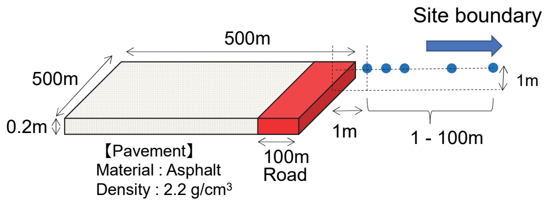

Figure 5. Road geometry for air dose rate evaluation.

2.3. Impact of radionuclide migrating to the ocean

When recycling material is used, it is assumed that dissolved radionuclides are transported out from recycling material. One-dimensional transport analysis based on partition equilibrium is conducted by clearance level evaluation code PASCLR2 for radionuclides migration [6]. In reusing for road, infiltration rate is determined on the assumption that rain infiltration to the ground. On the other hand, radionuclides elution from base of building is evaluated on the assumption that the base is submerged in aquifer and groundwater infiltrates to the base. The radionuclides concentration in the groundwater should be below the operation target value, which is 1 Bq/L for ^{134}Cs and ^{137}Cs, at the outlet to the ocean, respectively. We estimate the distance from boundary to be below the operation target value at outlet of the ocean.

Figure 6 shows a schematic chart of radionuclides migration from road. Evaluation is conducted by using reference concentration of the roadbed of concrete road, which has the highest concentration in four cases of road materials. In evaluation geometry, the roadbed is situated upon the aquifer and the pavement on the roadbed which usually prevents the rainfall from infiltrating into the ground is ignored conservatively. Radionuclides migrate from the roadbed to the aquifer as rainwater infiltrates roadbed vertically. Vertical infiltration rate is set to 0.4 m/y based on the infiltration rate observed at Hamadori in Fukushima prefecture [7].

Figure 7 shows a schematic chart of radionuclides migration from base. In evaluation geometry, the base is submerged in aquifer and filled with groundwater. Radionuclides migrate from base to aquifer by horizontal infiltration of groundwater. Groundwater infiltrates the base and flows out from the end of the base on the ocean side. Infiltration rate is set to 3.65×10^{-2} m/y on the assumption that the groundwater infiltrates through the cracks generated in the concrete.

This is the site-specific evaluation, on the other hand, and it has not been decided where to use the recycling material in the 1F site. Therefore, it is better to set the parameters with margin for safety side. We have tried to make our evaluations reasonable by setting the parameters which are chosen taking the 1F situation into accounts. In both cases, radionuclides migration is evaluated taking into account reported groundwater situation in the 1F site. The aquifer thickness is set to 10 m and the flow velocity of groundwater is set to 36.5 m/y [8].

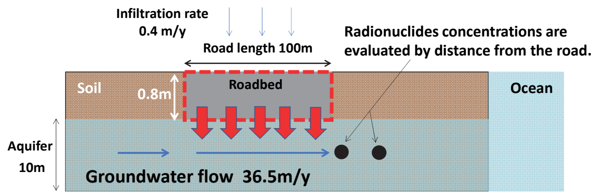

Figure 6. Analytical condition for radionuclides migration from road.

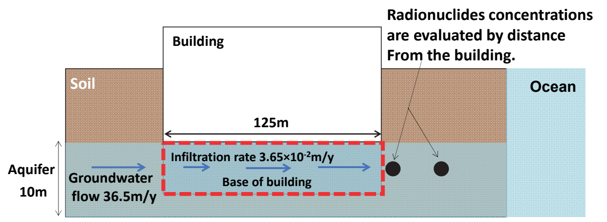

Figure 7. Analytical condition for radionuclides migration from base.

3. Calculation results

3.1. Additional annual dose for workers

When the recycling material was used for road materials, maximum additional dose was 1.2 mSv/y for driver in situation of reusing for concrete roadbed. Internal exposure by total Cs for worker was less than 5.0×10^{-5} mSv/y and it was significantly small compared with external exposure. The results indicated that additional annual dose for workers were less than 2 mSv/y which was 10 % of the dose limit.

When the recycling material was used for base of building, additional dose by external exposure was 1.3 mSv/y. The results indicated that additional annual dose for worker was less than 2 mSv/y.

It is confirmed that decommissioning activities are not restricted by reuse of contaminated rubble for road material and base of building.

3.2. Impact to air dose rate at the site boundary

Figure 8 shows the calculated results of air dose rate by the distance from road constructed by recycling material. Air dose rate decreases with distance from road, and the dose rate was below 0.4 mSv/y at 25 m from road. Annual doses were less than 0.6 mSv/y at many boundary points. Therefore, it is suggested that the annual dose at the site boundary are below 1 mSv/y under the condition that the road is located at a distance of more than 25 m from the 1F site boundary.

In the case of base of building, impact to air dose rate at 1 m from building was significantly small. Because the base is situated at the 9 m below the ground surface, air dose rate is significantly low even at the 1 m from building. The results indicated that the using of recycling material for the base does not have significantly impact on air dose rate at the site boundary.

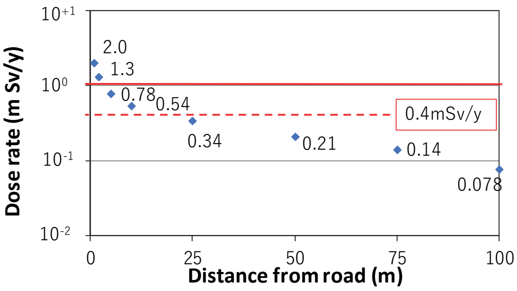

Figure 8. Impact on air dose rate corresponding to the distance from the site boundary to the road.

3.3. Impact of radionuclide migrating to the ocean

Figure 9 and **Figure 10** show ^{134}Cs and ^{137}Cs concentration in groundwater by using recycling material for the road. Concentrations are calculated by distance from the road. ^{134}Cs concentration is below the 1 Bq/L at the 0 m, which is operation target value of ^{134}Cs. ^{137}Cs concentration is over the 1 Bq/L at 0 m, which is operation target value of ^{137}Cs. Cs has high distribution coefficient (Kd = 2.7×10^{2} mL/g) in soil, therefore radiocesium migration is delayed in groundwater and decay of radiocesium occurs during migration. At 5 m, the concentration is below the 1 Bq/L. The results indicated that a distance of 5 m is needed from road to satisfy the target value at the outlet to the ocean.

Figure 11 and **Figure 12** show ^{134}Cs and ^{137}Cs concentration in groundwater by using recycling material for base. Concentrations are calculated by distance from building. At the 0 m from building, ^{134}Cs and ^{137}Cs concentrations are over 1 Bq/L. At the 5 m, both nuclides concentrations are below the 1 Bq/L. The results indicated that a distance of 5 m is needed from building to satisfy the target value at the outlet to the ocean.

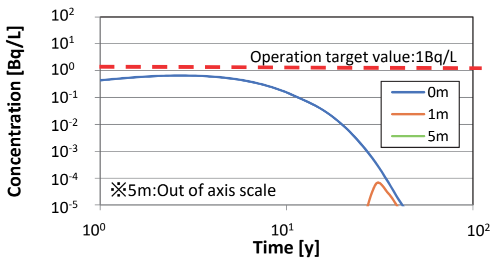

Figure 9. ^{134}Cs concentration in groundwater (road).

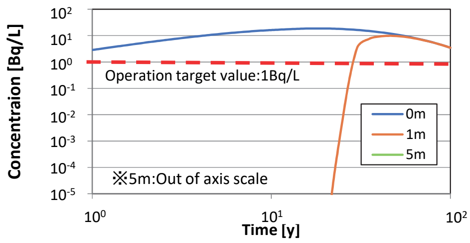

Figure 10. ^{137}Cs concentration in groundwater (road).

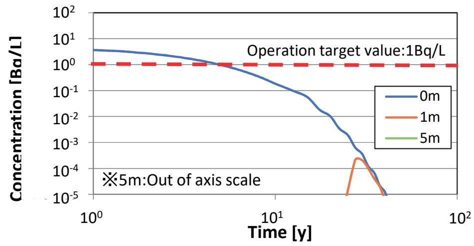

Figure 11. ^{134}Cs concentration in groundwater (base).

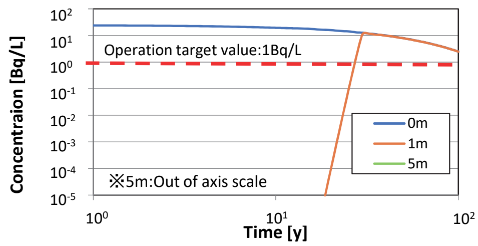

Figure 12. ^{137}Cs concentration in groundwater (base).

4. Conclusion

Rubbles with less than 5 μSv/h of surface dose rate, which are stored outdoor in the Fukushima Daiichi NPS (1F) site, will be recycled and applied in a restricted reuse only within 1F site in the future. We suggested a methodology for establishing the reference radioactive concentration of recycling material [2]. In this study, we studied the evaluation methodology for the validation of these reference concentrations considering the current situation of radiation protection in the 1F site similar to the planned exposure situation.

Additional worker dose was calculated as 1.3 mSv/y, smaller than 2 mSv/y, 10 % of dose limit. Annual dose at the boundary was below the 1 mSv/y with condition of more than the distance of 25 m from the road. Calculated radiocesium of ^{134}Cs and ^{137}Cs concentrations in the groundwater at the outlet to the ocean were the below the 1 Bq/L with condition of distance of more than 5 m from the building. The calculated results indicated that the reference radiocesium concentrations of recycling material were validated for the reuse of contaminated rubbles within the 1F site.

Acknowledgements

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