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論文題目	MODELING THE FLUX OF RADIOCESIUM REDISTRIBUTION IN A RIVER CATCHMENT FOLLOWING FUKUSHIMA NUCLEAR POWER PLANT ACCIDENT BASED ON THE WASH-OFF PROCESS （福島原発事故後の河川流域中放射性セシウム再分配流れの洗い落としプロセスに基づくモデル化）		

（論文内容の要旨）

This thesis presents the study of radiocesium redistribution in the river catchment scale and urban scale after Fukushima Daiichi Nuclear Power Plant accident.

Chapter 1 Introduction describes the background that motivates this research to be carried out, the objectives, the study area and the systematics of this research.

Chapter 2 reviews the past models that had developed since the early 1960s including the models of radionuclide movement developed during the three major radioactive substance's contamination (Nuclear weapon test, Chernobyl accident and Fukushima accident). This chapter also explains the types of wash off coefficient that used as a basic process in the model proposed in this research. In addition, the parameters value as the results of various previous studies are presented in this chapter. At the end, the evolution of the models of radiocesium movement in a river catchment is assessed.

Chapter 3 Modelling radiocesium flux in the catchment scale for rivers in Fukushima region explains the model that has been developed in this research. The test of the model in which the calculated values were compared with the observed data is presented. According to the comparison, the value of R^2 of 0.86 and the Nash efficiency coefficient value (n) of 0.85 were achieved for both ^{137}Cs and ^{134}Cs indicating the model could accurately predict the seasonal variation and the amount of the flux. This chapter also estimates the flux of radiocesium from Abukuma River and the other 16 rivers in Fukushima into the Pacific Ocean for long term period and analyses the effect of land use composition a river catchment. It was estimated that about 197-222 TBq of radiocesium will enter the Pacific Ocean from the Abukuma River and the other 16 rivers in Fukushima in 100 years after the accident. It was also found that the river catchments with wider forest area tend to release radiocesium at a lower rate. On the contrary, catchment areas with wider urban area would release radioesium at a higher rate.

Chapter 4 firstly describes the behavior of radiocesium in the sludge of a sewer system. Thereafter, the possible sources of the radiocesium infiltration to a sewer system are identified. Each of the possible sources is confirmed by a specific analysis in the last part of the chapter. Based on the daily radiocesium concentration in sewer sludge and daily rainfall depth, the strong correlation between them was observed. In every after a rainfall event, the flow rate in WWTP increases and followed by the elevation of the radiocesium concentration. Hence there is an indication that radiocesium was brought from rain derived inflow infiltration (RDII). It was estimated that about 1.7 % of surface run off as a result of rainfall enters the separate sewer system. Moreover, as found by some previous studies that people in Fukushima city were orally exposed by 0.2-17.3 Bq/day of radiocesium in their food, the other source of radiocesium contamination could be the excrement from the residence in Fukushima city.

Chapter 5 explains the fate of radiocesium in a waste water treatment plant (WWTP). The flux of the radiocesium from each stage in the WWTP is analyzed. This chapter also analyzes the removal rate the

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radiocesium in domestic WWTP. it was found that the fate or radiocesium is likely different depending on the meteorological condition. During dry weather about more than 80% of the radiocesium was removed from waste water and transferred into sludge form. On the other hand, during wet weather, the removal rate of radiocesium decreases as the efficiency of the WWTP also decreases. It was estimated based on the result of the second campaign, about 70% of radiocesium was separated from the waste water and concentrated in sludge form.

Chapter 6 describes the model that has been developed to quantify the movement of radiocesium in urban area and its infiltration to a separate sewer system in Fukushima and Koriyama city. The accuracy of the model is evaluated by the observed data. The result of the model for both urban areas (Fukushima and Koriyama) shows a satisfactory result. For Fukushima city case, with R^2 value of 0.85 and *n* value of 0.81 for ^{134}Cs and 0.82 for ^{137}Cs whereas in Koriyama city WWTP case, with R^2 value of 0.86 and *n* value of 0.81 for ^{134}Cs and 0.78 for ^{137}Cs, 96% of the estimated value are in the range of 10-90 percentiles of the observed data. Based on the calculation, RDII was the most dominant process causing the infiltration of radiocesium particularly in the early phase after the accident. However, during dry weather periods, the contribution of radiocesium infiltration from human excretion increases.

Chapter 7 aims to analyze the reliability of the model during a condition where the availability of the input data is limited. Moreover, the most sensitive wash off parameter was also identified in this chapter. Three scenarios were established. Scenario A, B and C randomly select 100, 500 and 1,000 values respectively from the 200,000 spatial data of radiocesium fall out resulted from a survey by MEXT. Based on the distribution of *n* values, there is a clear difference among the scenarios. Scenario B and C gives probability to obtain the estimated data with accuracy $n>0.7$ about 95%, Scenario A only gives the probability about 86%. This indicates that by using scenario B and C, consistently accurate estimated data could be obtained. Finally, the sensitivity analysis of the wash off parameters used in this model was analyzed. The Monte-Carlo simulation was applied for each wash off parameter range. About 1,000 values were chosen for each range. The results show that the most sensitive wash off parameters are the liquid wash off in the built urban area, solid wash off in agriculture area and liquid wash off in forest area

Chapter 8 summarizes all the important findings are summarized and emphasized. Finally, the uncertainties and limitations of this study were describe to open the opportunities for improving the model developed in this research are described.

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（論文審査の結果の要旨）

本論文は、福島第一原発事故によって放出され、地表面に沈積した放射性 Cs の挙動を、河川集水域と、特に都市部の下水道整備区域について、実測データと数値シミュレーションから明らかにしたものである。得られた主な成果は以下のとおりである。

１）阿武隈川とその周辺 16 河川の流域における放射性セシウムの挙動をシミュレーションするためのモデルを、コンパートメントモデルを用いて作成している。シミュレーション区域を 29 のサブ流域と 9 河川区分に分割し、洗い落とし項を ArcMAP のインターフェースと結合させた SWAT モデルを用いて推定し、その洗い落とし項をモデルに考慮することによって、実測値と良く一致する環境中セシウム濃度のシミュレーションが可能であることを示した。また、阿武隈川からのセシウム 137 の 100 年間における海洋への総流出量は 111TBq 程度であること、また、一般に市街地面積が広い流域の方が、森林面積が広い場合よりも放射性セシウムの流出が多いことなどを示した。

２)チェルノブイリ原発事故後に開発された合流式下水道への放射性物質の流入シミュレーションモデルを改良し、放射性物質の流入因子として、降雨の流入によるものの他に、人の排泄物や汚染した衣服からの影響も考慮することで、分流式下水道への放射性セシウムの流入量、および下水汚泥中放射性セシウム濃度の推定値が、福島における実測データの経時変化を良い精度でシミュレーションできることを示した。

３）開発したモデルにモンテカルロ法を利用した感度解析を実行した結果、推定に用いる放射性セシウムのフォールアウトデータ数は、推定精度にあまり大きな影響を及ぼさないこと、都市域と森林域において最も敏感な洗い落としパラメーターは液体状での洗い落としに関するパラメーターであり、農地においては粒子状での洗い落としに関するパラメーターであること、また、本モデルでは土地利用用途の面積の割合が重要な因子であることなどを示した。

以上のように本論文は、今後の福島における放射能汚染レベルの変化を精度良く推定する方法を提案するものであり、福島での除染目標の設定などに大きく貢献するものであって 、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成２７年８月２６日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。

なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、当該論文の全文に代えてその内容を要約したものとすることを認める。