Dose assessment for the future use of the former temporary storage sites

1. Introduction

In March 2011, the accident at TEPCO's Fukushima Daiichi Nuclear Power Station caused radioactive materials to be dispersed, contaminating large areas of Fukushima and other parts of eastern Japan. In order to recover the environment from radioactive contamination, decontamination work is being carried out in the living areas mainly in accordance with "Act on Special Measures concerning the Handling of Pollution by Radioactive Materials". As shown in Figure 1, decontamination in Fukushima Prefecture is carried out in two main categories: the special decontamination areas (SDA) where the national government formulates a decontamination implementation plan and decontamination projects are carried out, and the intensive contamination survey areas (ICSA) where municipalities formulate a decontamination implementation plan and decontamination projects are carried out. Whole area decontamination based on the Act on Special Measures was completed by March 2018, excluding the difficult-to-return zone in SDA.[1]

The soil and waste removed in Fukushima Prefecture as a result of decontamination activities are stored at temporary storage sites (TSSs), etc., and then transported to Interim Storage Facility, where they will be safely and centrally managed and stored until final disposal is performed outside Fukushima Prefecture. After the soil and waste has been removed from the TSS, the TSS will be restored to their original condition based on the land-use before the TSS was created (Land feature will be restored.) During the restoration work, it is checked that there is no obvious contamination due to the storage by the measurement of the air dose rate by the manager of the TSSs (mainly local municipalities) before the return to the landowners. If contamination is confirmed, decontamination should be carried out following the guidelines established by the Ministry of the Environment.[2, 3]

When the TSSs are returned to the landowners after restoration, the results of exposure dose assessment in the TSSs can be presented to the landowners to effectively certify the present day safety of the TSSs. Considering the role of Fukushima Prefecture for supporting the municipalities, it is particularly important to assess the current and potential future additional exposure doses from use of the land at the former TSSs in ICSA.

This study establishes a method to assess the additional exposure dose associated with the potential future use of the former TSS after restoration. Various potential land-uses, assessment scenarios, calculation models and parameters were examined, and the additional exposure dose per unit concentration of radioactive cesium (1 Bq/kg) was calculated. These results can then be used to assess the additional potential future dose at each TSS according to the concentration of radioactive cesium in soil at site. Uncertainty in the level of additional dose was assessed by comparing the results of calculations using average values for parameters such as exposure time and food intake with those using conservative values. Furthermore, the additional exposure doses were calculated on a case study basis using the measured cesium concentration values and air dose rates in the topsoil of the actual TSS, and compared with 1 mSv/year *1 which is the target value of the additional exposure doses.

After describing the background of the assessment and information on the TSS and its restoration, the assessment scenarios were examined and assessed considering various possibilities. Reference is made to the IAEA document, General Safety Guide No. GSG-3[4] (hereinafter referred to as "GSG-3") and Safety Guide No.WS-G-5.1 [5](hereinafter referred to as "WS-G-5.1"). GSG-3 provides recommendations to meet the safety requirements of the IAEA document General Safety Requirements Part 5[6]. GSG-3 states that the reliability of the assessment results can be improved by combining the probabilistic and deterministic approaches. However, in order to use a probabilistic approach, it is necessary to understand the probability distribution of the parameter values, but such data are not available. Therefore, although this study did not undertake a probabilistic approach, the reliability of the assessment was improved by assessing the exposure dose using parameter values such as mean values and evaluating the effect of the uncertainty in these parameter values by considering their variability. The flow diagram of this study is shown in Figure 2.

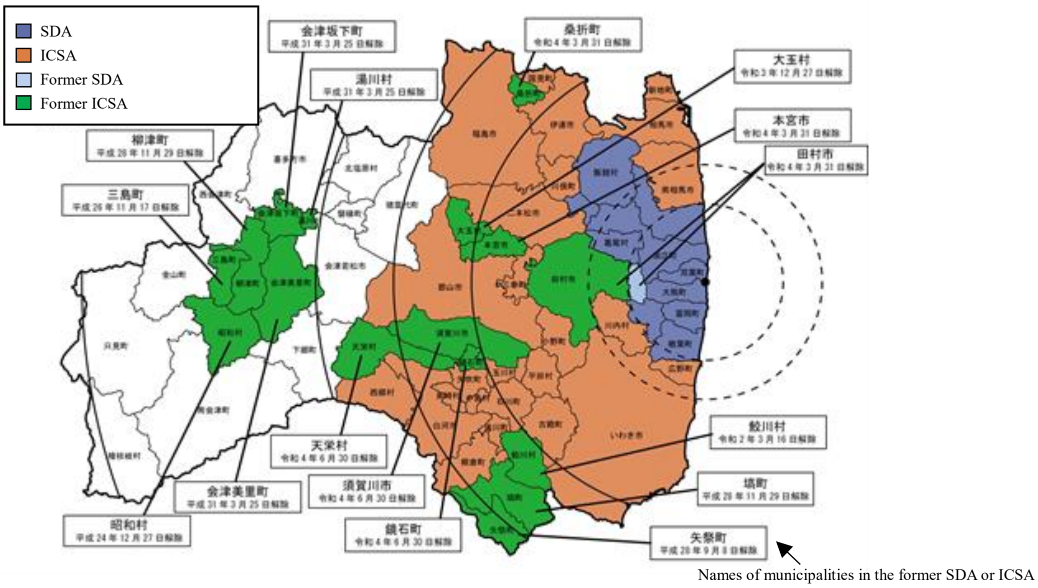


Figure 1. ICSA in Fukushima Prefecture [7]

*1 The basic policy based on the Law Concerning Special Measures against Radiation Contamination states that the long-term goal is that the additional exposure dose (exposure to artificial radionuclides) should be less than 1 mSv/year. This is the same value as the ICRP recommended public exposure dose limit of 1 mSv/year.

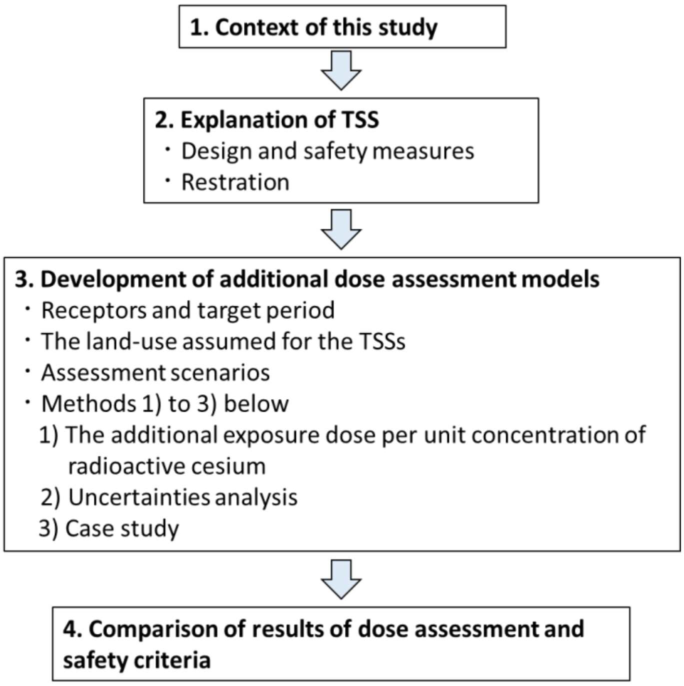


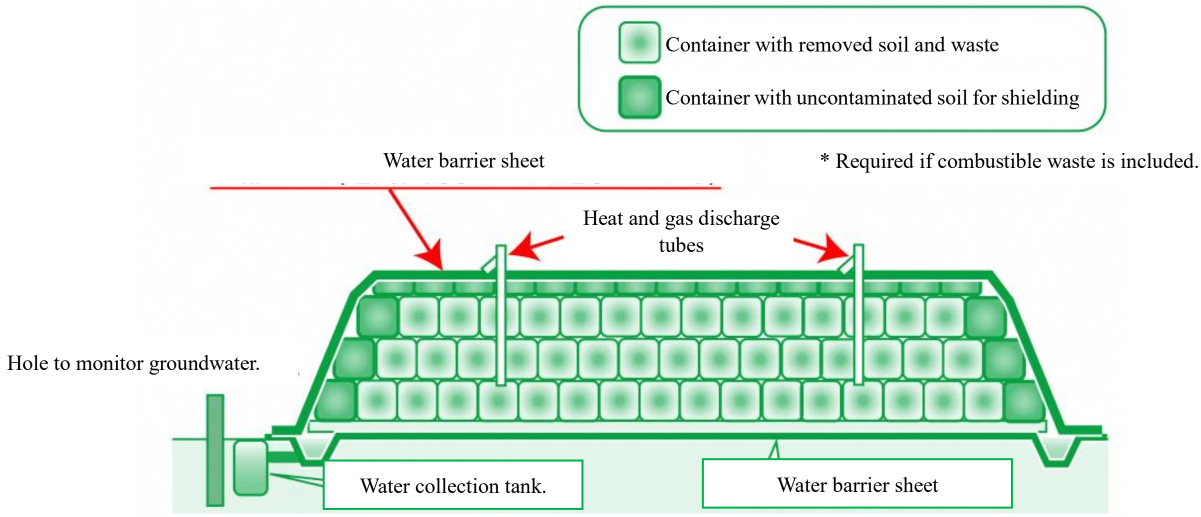
Figure 2. Flow diagram of dose assessment in the present study

2. Design, safety measures and restoration of TSS

The TSSs for removed soil and waste are designed and managed in accordance with the guideline[2] established by the Ministry of the Environment. In the guideline, in order to achieve the safe storage of the removed soils and wastes, the TSS has seven facility requirements for the safe storage: 1) shielding and isolation, 2) prevention of dispersion of the removed soil and waste, 3) prevention of penetration of rainwater, etc., 4) prevention of outflow of the removed soil, waste and radioactive materials, 5) prevention of effect from substances other than radioactive materials, 6) resistance to earthquake, etc., 7) other necessary measures, and three management requirements: 1) restriction of entry, 2) monitoring the radiation dose and carrying out repairs, 3) keeping records. Figure 3 shows the design and structure of a typical above-ground TSS. At TSSs, the measurements of air dose rates and other data are carried out before the beginning of the storage of the removed soil and waste, during storage and after the stored soil has been removed.

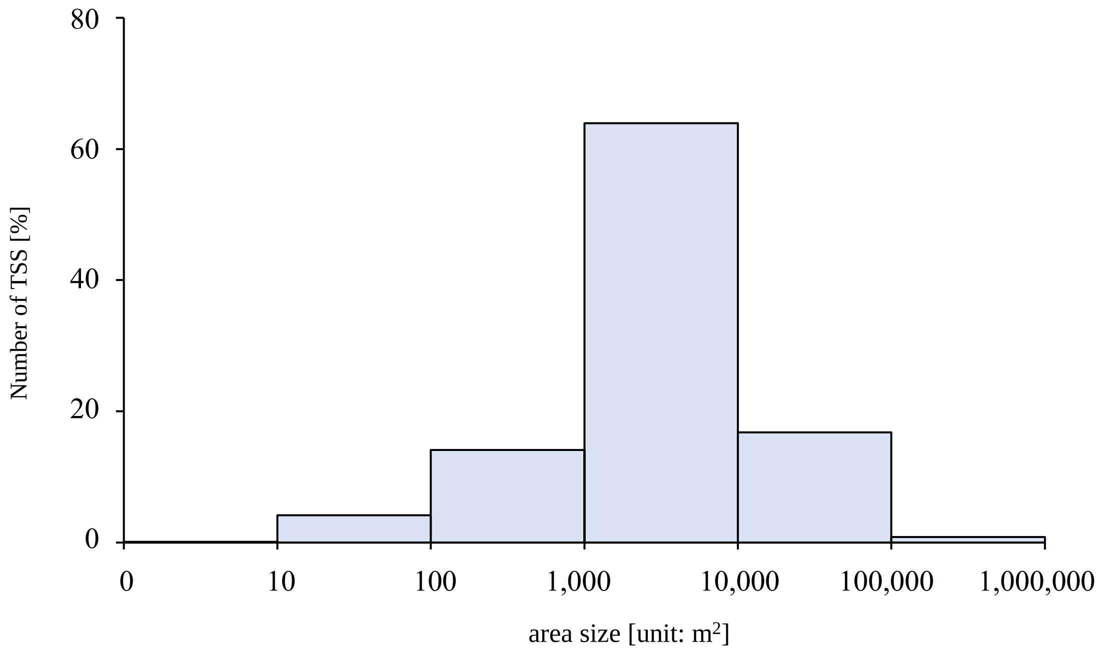
The distribution on the area size of TSSs in ICSA is shown in Figure 4. Over 60% have areas between 1,000 m^2 and 10,000 m^2. The information on the size and the land use before the land was developed as the TSS is shown in Table 1 and it was mainly used as agricultural land (e.g. paddy field or field), forest or park.

The transportation of the removed soil and waste from the TSSs to the Interim Storage Facility and their restoration are still in progress. The return of the land of former TSS to the landowners has already been completed at many sites in Fukushima Prefecture. Figure 5 shows the number of TSSs in the ICSA.



Source: Decontamination information website - Temporary storage area

Figure 3. Basic design and structure of TSS [8]



Source: Decontamination Countermeasure Division Fukushima Prefectural Government

Figure 4 Area size distribution of TSSs for ICSA in Fukushima Prefecture

Table 1. Original land-use and area size of TSSs in ICSA

original land-use	Number of TSS with known original land use and area size	area size [unit: m^2]		
		mean	minimum	maximum
Paddy	232	8,511	182	129,079
Cropland	282	5,333	10	55,853
Pasture	10	54,371	500	363,000
Forest	104	11,775	15	122,000
Park	70	1,828	9	20,000
The other (parking lots, etc.)	122	10,484	15	360,871
Total	821	8,204	9	363,000

Source: Decontamination Countermeasure Division Fukushima Prefectural Government

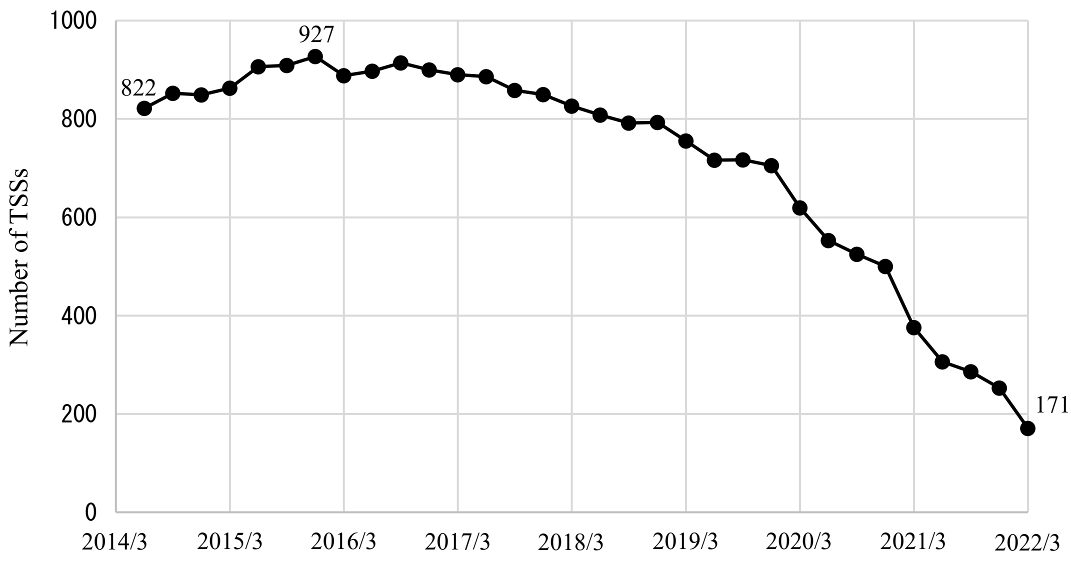


Figure 5. Number of TSSs of ICSA in Fukushima Prefecture over time [9]

The restoration of the TSSs is carried out in accordance with the guidelines [2, 3] established by the Ministry of the Environment. When the movement of the stored soil and waste has been completed, the TSSs will be restored to the original state[*2] following the process shown in Figure 6 and returned to the landowner.

The restoration of the TSSs is basically to restore the original land state before the TSS. That is, where the shape of the land was changed to enable its usage as a TSS, it will be returned to its previous shape. In addition, the function of the land will be restored so that the usage of the land[*2] will not be hindered.

Although the TSS is designed to prevent contamination of the topsoil with radioactive materials, under the incidental event of a leak of radionuclide during transport or storage of removed soil

*2 The land use may be changed to a different land use than before the TSS was established, depending on the wishes of the land owner.

and waste, the topsoil might become contaminated with radionuclides. After the removal of soil and waste from the TSS and the removal of the structures of the TSS, the air dose rates and/or cesium concentrations in topsoil are measured to confirm that there is no local contamination of the land. The measurement points are basically the centre position of the area where the soil and waste placed and one point at each of the four corners of the TSS. If there are multiple the areas within one temporary storage area, measure the center and four corners of each.

Determine the presence or absence of contamination by comparing measurements taken after soil removal with measurements taken before TSS establishment, during management of its or on the surrounding decontaminated land of the same land-use. If localized contamination is found, topsoil removal, etc. should be performed by the Municipality. After all restoration work is completed, air dose rates, and/or cesium concentrations in topsoil are measured again.

All results of the air dose rate and other measurements are recorded and presented when the land is returned to the landowner after the restoration is completed.

In the flow diagram of restoration of the TSS shown in the guideline[2] established by the Ministry of the Environment, the measurement of the air dose rates is supposed to be conducted. Although the additional exposure assessment is not included.

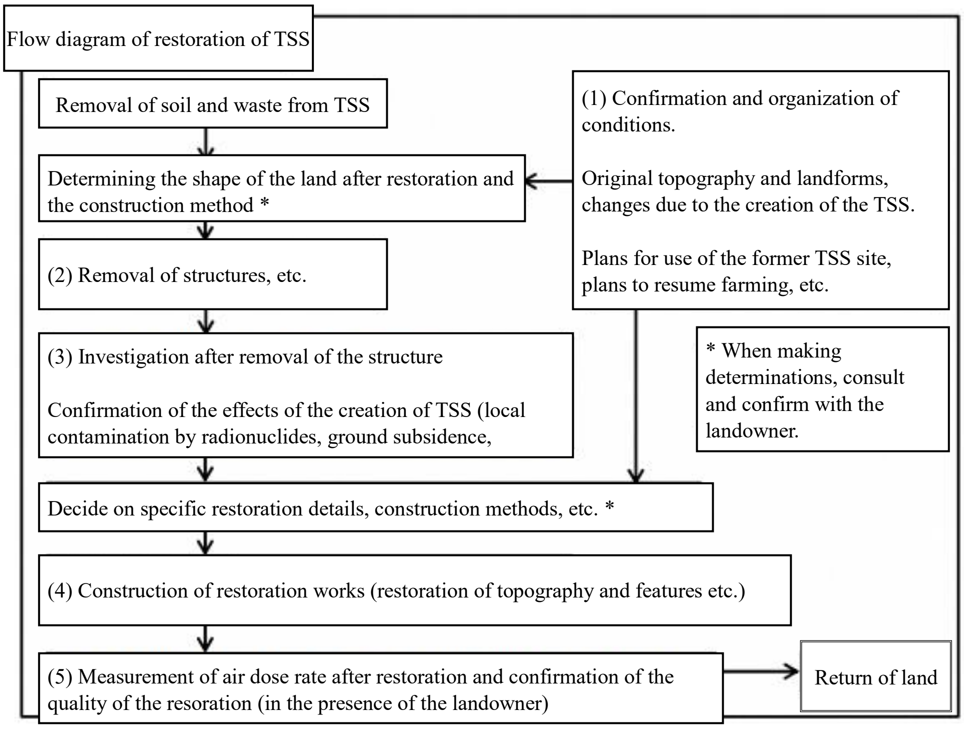


Figure 6. Flow diagram of restoration of TSS [2]

3. Assessment model

3.1. Target persons and period for assessment

The target of the assessment is future users of the former TSS site in ICSA. Since the values of dose conversion factors, food intake, exposure time, etc. differ depending on the age of the users, the age groups of the target persons were divided into adults (over 20 years old) and minors, and the minors were subdivided into 1-6 years old, 7-14 years old and 15-19 years old. The assessment was conducted using the appropriate parameter values for each age group. Due to radionuclide decay, the radionuclide concentrations in the environment will generally decrease with time. The exposure of people to radionuclides will depend both on the concentrations of radionuclides and the activities of the people at the former TSS. For example, forestry work may cause people to receive varying exposures with time and the maximum exposures may not occur at the start of the assessment period. For these reasons we have assessed the factors that could lead to exposure doses to be higher in some years.

3.2. Assessment scenarios

As recommended in GSG-3 and WS-G-5.1, the assessment scenarios were developed in order to perform the exposure dose assessment. In addition, since it is stated that potential hazards should be considered in the assessment scenarios, various possibilities were considered.

In order to create an assessment scenario according to the land use of the former TSSs, the land use which could be considered in the former TSS was examined. The TSSs are basically restored to the land-use and shape prior to the installation, but may be changed to a different shape than before depending on the intentions of the land owner. Therefore, not only the conventional land-use of agricultural land, forest, park and parking lot, but also other potential land-uses such as housing, factories, commercial facilities, and material storage areas were considered as shown in Figure 7 .

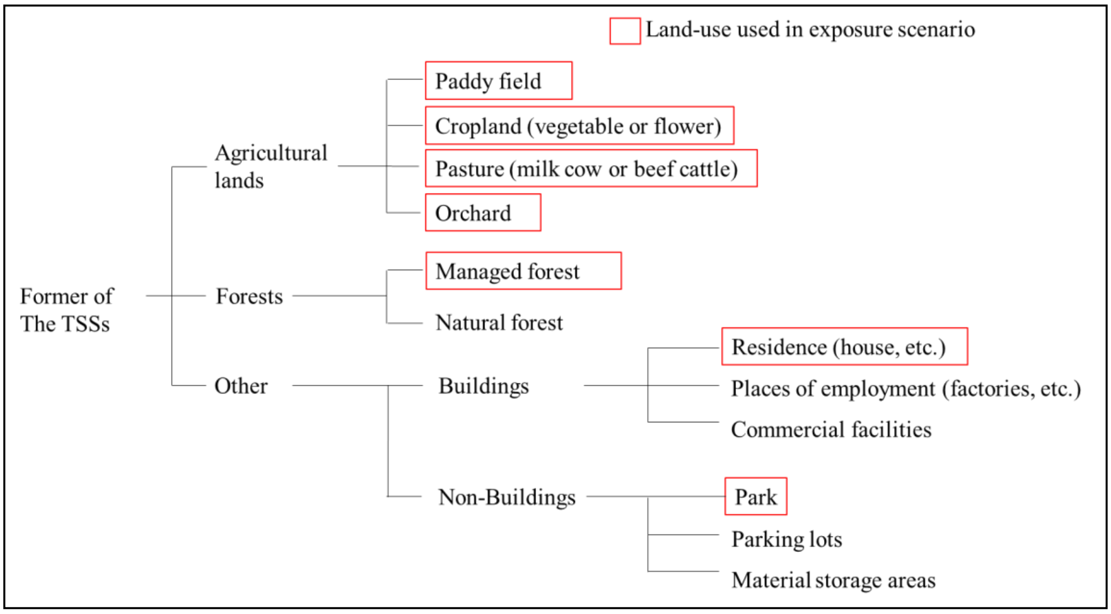


Figure 7: The land-use assumed for the former TSS

The agricultural land scenario was categorized into paddy, cropland, pasture and orchard scenarios. The cropland scenario was subdivided into two scenarios: a vegetable scenario with the internal exposure due to food intake and a flower scenario with long working hours leading to external exposures. The pasture scenario was subdivided into two: milk cow and beef cattle. For the forest scenario, managed forest and natural forest scenarios were considered, but only the managed forest scenario was assessed because it takes a very long time for the former TSS to become close to a natural forest condition, and the radionuclides are undergoing radioactive decay during that period. Among other land uses, for buildings, residential areas (houses, etc.), places of employment (factories) and commercial facilities were considered, but only the scenario of housing was assessed because the exposure time of persons would be the longest. For the "non-building" scenarios, park, parking lots and material storage areas were considered, but only the scenario of the park where the person's exposure occupancy time would be the longest was assessed. These nine types of scenarios are shown in Table 2.

For each scenario, the exposure pathways depending on the land-use are defined by the Atomic Energy Society of Japan (AESJ) Standard Safety Assessment Methodology for Shallow Subsurface Disposal: 2016 [10] (hereinafter referred to as the "AESJ Standard") and the IAEA Safety Reports Series No. 44 [11] (hereinafter referred to as "SRS No. 44"). Common exposure pathways which were included for all scenarios were: the external exposure during activities and occupation of the former TSS, the internal exposure due to unintentional ingestion of soil at the former TSS, and the internal exposure due to inhalation of soil and dust generated from TSS. Regarding the internal exposure due to the intake of food from the former TSS, the intake of crops in the Paddy scenario, the Cropland (vegetable) scenario, and the Orchard scenario, the intake of milk in the Pasture (milk cow) scenario, and the intake of crops from kitchen garden in the Residence scenario were also included. Monitoring of drinking water (including well water) in Fukushima Prefecture [12] has not detected radioactive cesium, therefore, exposure due to ingestion of water from the former TSS was excluded from the assessment in the present study. An illustration of the different exposure pathways is shown in Figure 8.

In the Pasture (beef cattle) scenario, the intake of beef from cattle that had grazed on the former TSS was considered to be possible, but as slaughter is not allowed except in licensed slaughterhouses under the law, it was judged that a farmer would not consume beef that grazed on their former TSS. For that reason, the internal exposure due to the beef intake was not included. It is known that there have been no cases of cattle being raised in barns built on the site of TSSs (Source: Decontamination Countermeasure Division Fukushima Prefectural Government). However, since it cannot be ruled out that there may be cases of cowsheds being built in the future, the assumption of raising cattle on the site of the TSS was included in the Pasture (milk cow and beef cattle) scenarios.

In the forest scenario, the intake of mushroom and wild plants is possible but these are mainly taken in natural forests [13]. Therefore, the intake of mushrooms and wild plants from the former TSS was excluded from the assessment in the present study.

Where the scenario considers adults working on the land, such as agricultural land and forest, it is assumed that children may accompany the adult workers, so the above scenarios and exposure pathways are set to be common to all age groups.

Table 2. List of land-use scenarios and respective exposure pathways

No.	Land-use	activity	Exposure pathway
1	Paddy	Grow and consume rice	1) External exposure of workers during rice cultivation 2) Internal exposure of workers due to ingesting the grown rice 3) Internal exposure of workers due to ingestion of soil during rice cultivation 4) Internal exposure of workers due to inhalation of dust generated during rice cultivation
2	Cropland (vegetable)	Grow and consume vegetables	1) External exposure of workers during vegetable cultivation 2) Internal exposure of workers due to ingesting the grown vegetable 3) Internal exposure of workers due to ingestion of soil during vegetable cultivation 4) Internal exposure of workers due to inhalation of dust generated during vegetable cultivation
3	Cropland (flower)	Grow flowers	1) External exposure of workers during flower cultivation 2) Internal exposure of workers due to ingestion of soil during flower cultivation 3) Internal exposure of workers due to inhalation of dust generated during flower cultivation
4	Orchard	Grow and consume fruit	1) External exposure of workers during fruit cultivation 2) Internal exposure of workers due to ingesting fruit 3) Internal exposure of workers due to ingestion of soil during fruit cultivation 4) Internal exposure of workers due to inhalation of dust generated during fruit cultivation
5	Pasture (milk cow)	1) Grow the pasture at TSS 2) Feed the pasture to the milk cow at the INSIDE of TSS	1) External exposure of workers during raising milk cows 2) Internal exposure of workers due to consuming milk from cows raised

		3) Consume the milk	3) Internal exposure of workers due to ingestion of soil during raising milk cows 4) Internal exposure of workers due to inhalation of dust generated during raising milk cows
6	Pasture (beef cattle)	1) Grow the pasture at TSS 2) Feed the pasture to the beef cattle at the INSIDE of TSS	1) External exposure of workers during raising beef cattle 2) Internal exposure of workers due to ingestion of soil during raising beef cattle 3) Internal exposure of workers due to inhalation of dust generated during raising beef cattle
7	Managed Forest	Forest management	1) External exposure of workers during forestry work 2) Internal exposure of workers due to ingestion of soil during silvicultural work. 3) Internal exposure of workers due to inhalation of dust generated during silvicultural work.
8	Residence	1) living the house built at the TSS 2) manage kitchen garden*3 and consume the vegetable	1) External exposure during living indoors 2) External exposure during kitchen gardening 3) Internal exposure due to ingestion of vegetable grown from kitchen garden 4) Internal exposure due to ingestion of soil during kitchen gardening 5) Internal exposure due to inhalation of dust generated during kitchen gardening
9	Park	Stay at the park	1) External exposure while staying in the park 2) Internal exposure due to ingestion of soil while staying in the park 3) Internal exposure due to inhalation of dust generated while staying in the park

*3 Although there are many possible varieties of outdoor work on a residential property, kitchen garden was considered representative for the assessment in the present study.

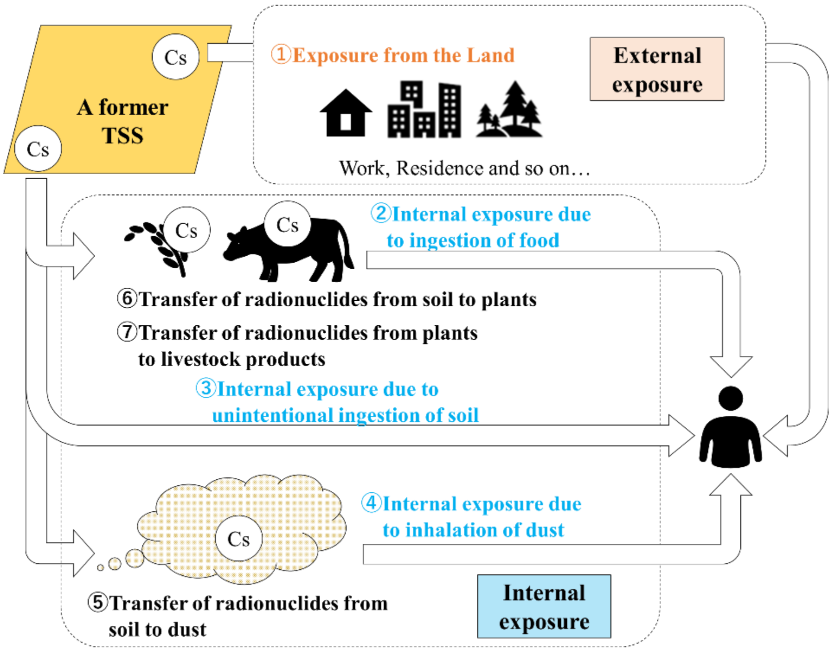


Figure 8. Illustration of potential exposure pathways

3.3. Calculation models and parameters

In assessing the additional exposure doses from the potential future use of the former TSSs, the calculation models used are shown (Formula 1 to Formula 8, and these are based on the formulae given in) derived from the AESJ Standard and SRS No.44. The internal exposure model for soil ingestion, shown in Formula 3 is based on, the internal exposure model for food ingestion shown in Formula 2. For the internal exposure model for soil ingestion in Formula 3, and also for the model for the radionuclide transfer from soil to airborne dust shown in Formula 5, an additional parameter was included to account for the tendency that the concentration of radionuclide tends to increase as the particle size becomes fine - SRS No. 44.

Formula 1. External Exposure

$D_{ext}(i) = C_s(i) S_s(i) t_s D_{CF,EXT}(i)$

$D_{ext}(i)$: External radiation dose from radionuclide i ［Sv/year］

$C_s(i)$: Radionuclide i concentration in soil ［Bq/kgDW］

$S_s(i)$: Radionuclide i shielding factor (screening factor) [-]

t_s : Exposure time (Annual activity time) ［h/year］

$D_{CF,EXT}(i)$: Conversion factor of external exposure dose due to radionuclide i ［(Sv/h) / (Bq/kgDW)］

Formula 2 internal exposure due to food ingestion

$D_{ing,f}(i) = C_f(i) M_f G_f D_{CF,ING}(i)$

$D_{ing,f}(i)$: Internal radiation dose due to the oral intake of radionuclide i ［Sv/year］

$C_f(i)$: Radionuclide i concentration in food ［Bq/kgFW］

M_f : Annual amount of food intake ［kgFW/year］

G_f : Market dilution factor of food [-]

$D_{CF,ING}$: Conversion factor of internal exposure dose due to the oral intake of radionuclide i ［Sv/Bq］

Formula 3 Internal exposure due to soil ingestion

$D_{ing,s}(i) = C_s(i) f_{c,s} M_s t_{s,ing} D_{CF,ING}(i)$

$D_{ing,s}(i)$: Internal radiation dose from radionuclides i due to the oral intake of soil [Sv/year]

$C_s(i)$: Radionuclide i concentration in soil [Bq/kgDW]

$f_{c,s}$: Concentration factor of specific activity in the fine fraction for soil ingestion [-]

M_s : Soil intake per hour [kgDW/h]

$t_{s,ing}$: Soil ingestion time in former TSS [h/year]

$D_{CF,ING}(i)$: Conversion factor of internal exposure dose due to the oral intake of radionuclide i [Sv/Bq]

Formula 4 Internal exposure due to dust inhalation

$D_{inh}(i) = C_a(i) B_A t_{s,inh} D_{CF,INH}(i)$

$D_{inh}(i)$: Internal radiation dose due to the inhalation of radionuclide i ［Sv/year］

$C_a(i)$: Airborne radionuclide i concentration ［Bq/m^3］

B_A : Breathing rate ［m^3/h］

$t_{s,inh}$: Dust inhalation time in former TSS ［h/year］

$D_{CF,INH}(i)$: Conversion factor of internal exposure dose due to the inhalation of radionuclide i ［Sv/Bq］

Formula 5 Radionuclide transfer from soil to airborne dust in air

$C_a(i) = C_s(i) f_{c,d} d_R$

$C_a(i)$: Airborne radionuclide i concentration ［Bq/m^3］

$C_s(i)$: Radionuclide i concentration in soil ［Bq/kgDW］

$f_{c,d}$: Concentration factor of specific activity in the fine fraction for soil [-]

d_R : Airborne dust concentration ［$kgDW/m^3$］

Formula 6 Radionuclide transfer from soil to rice, vegetables and fruits

$C_{V,f}(i) = C_s(i) T_{R,f}(i)$

$C_{V,f}(i)$: Radionuclide i concentration in plant ［Bq/kgFW］

$C_s(i)$: Radionuclide i concentration in soil ［Bq/kgDW］

$T_{R,f}(i)$: Radionuclide i transfer factor (transfer from soil to agricultural product) ［(Bq/kgFW) / (Bq/kgDW)］

Formula 7 Radionuclide transfer from soil to pasture

$C_{V,p}(i) = C_s(i) T_{R,p}(i)$

$C_{V,p}(i)$: Radionuclide i concentration in pasture ［Bq/kgDW］

$C_s(i)$: Radionuclide i concentration in soil ［Bq/kgDW］

$T_{R,p}(i)$: Radionuclide i transfer factor (transfer from soil to pasture)［(Bq/kgDW) / (Bq/kgDW)］

Formula 8 Radionuclide transfer from pasture to livestock product

$C_{Ca}(i) = C_{V,p}(i) f_r M_g T_{AM}(i)$

$C_{Ca}(i)$: Radionuclide i concentration in livestock product ［Bq/kgFW］

$C_{V,p}(i)$: Radionuclide i concentration in pasture ［Bq/kgDW］

f_r : Market dilution factor of feed [-]

M_g : Feed intake by livestock ［kgDW/day］

$T_{AM}(i)$: Ratio of consumed radionuclide i transfer to livestock product ［day/kgFW］

Assessment generally used the average parameter suitable for each age group (adults, 1-6 years old, 7-14 years old, 15-19 years old) were used. For the dose conversion factors and transfer factors, the values described in Satoh, et al. report [14] and the IAEA and ICRP documents [15, 16] were used. For parameters for which the average value is unknown, the values described in the documents [10, 17] of the Atomic Energy Society of Japan and Technical Reports Series No. 472 [18] of the IAEA were used. The parameter values used for the assessment are shown in Appendix A, Tables A1-A10.

The radionuclides considered were cesium-134 and cesium-137, which have longer half-lives than other radionuclides released in the Fukushima Dai-ichi nucler power plant accident and were released into the environment in large quantities according to the Japanese government's reports [19]. The abundance ratio of cesium-134 and cesium-137 was calculated from the Japanese government's reports, taking into account radioactive radioactive decay, starting from an assumed a ratio of 1: 1 at the time of the accident.

The conversion factor of external exposure dose in Formula 1 depends on the depth distribution of radioactive cesium. The distribution of radioactive cesium in the soil of the TSSs depends on the construction method of the TSS, the land use of the site and the time elapsed since the accident. It is assumed that the depth distribution of radioactive cesium is exponentially distributed [20, 21] or has a peak at some depth if there is no artificial mixing or agitation (e.g. digging, ploughing) [22]. When there is artificial mixing or agitation the concentration of cesium in the soil profile is averaged [20].

When the radioactive cesium is exponentially distributed from the ground surface, the radioactivity concentration A_m (ζ) (Bq/kg) at the mass depth ζ (g/cm^2) is expressed by the exponential equation [23] (9) according to the radioactivity concentration $A_{m,0}$ (Bq/kg), the mass depth ζ (g/cm^2) and the relaxation mass depth β (g/cm^2).

$$A_m(\zeta) = A_{m,0}\exp(-\zeta/\beta) \quad \cdots\cdots \quad (9)$$

The mass depth ζ is defined as the product of soil depth (cm) and density (g/cm3). The relaxation mass depth β is a parameter representing the depth distribution of radioactive cesium, and the smaller the value, the more the radioactivity concentration is concentrated near the ground surface. Kato, et al. report [21] that the relaxation mass depth β on land without artificial mixing just after the accident becomes around 1 g/cm^2. On the other hand, according to the investigation conducted by the Nuclear Regulation Authority about 9 years after the accident, it is reported that the relaxation mass depth β was about 4 [24]. In this study, for calculating the exposure dose we assumed that the cesium is at the surface of the soil and so we set the external exposure dose conversion factor $D_{CF,EXT}(i)$ for the relaxation mass depth β to 1 g/cm^2.

3.4. Assessment Method of additional exposure dose from the former TSS with unit concentration of radioactive cesium

3.4.1. Assessment Method of using average and standard parameter values

The additional exposure dose per unit concentration of radioactive cesium in soil was calculated based on the scenarios, models and parameters set out in Sections 3.1 to 3.3. Regarding the concentration of radioactive cesium, the concentration of cesium-137, which has a long half-life and remains for a long time, was set to 1 Bq/kg as of June 2022. The concentration of cesium-134 was set to 0.03 Bq/kg in consideration of the radioactive decay that has occurred between the accident and June 2022 assuming a ratio of cesium-134 to cesium-137 at the time of the accident of 1.

However, in the Managed Forest scenario, the assessment results are presented for the logging performed in the 45th year[*4] after tree planting, considering the working time involved in harvesting and radioactive decay of cesium. The concentration of radioactive cesium after 45 years (June 2067) was calculated considering radioactive decay, and the concentration of cesium-137 was set to 0.36 Bq/kg and the concentration of cesium-134 was set to 8.2×10^{-9} Bq/kg.

3.4.2. Method of uncertainty analysis

The GSG-3 states that consideration of uncertainty is essential in safety assessment. Uncertainty exists in each of the assessment scenarios, models and parameters. As for the assessment scenarios,

*4 The standard number of years it takes to grow and harvest a cedar tree in Fukushima Prefecture is 45 years [25, 26, 27, 28].

we considered that uncertainty was addressed because the scenarios covered various cases considering various possibilities, and even if there is a change in land-use in the future, it would be covered by the scenarios discussed in Section 3.2. In addition, since the models refer to the AESJ Standard which are the documents of Japanese academic societies, and some of the calculation formulas are conservatively modified by referring to the IAEA documents [11], the uncertainty in the models was judged to be covered.

The parameter values set for the assessment of the additional exposure doses in Section 3.4.1 are average or standard values, but there are variations in each parameter value and it is necessary to consider uncertainty. Therefore, uncertainty was examined by evaluating the additional exposure dose with conservative parameters used for the assessment of the additional exposure dose per unit concentration of radioactive cesium in Section 3.4.1. However, GSG-3 notes that a conservative assessment may show results that are not realistic, and caution is needed in their interpretation. The parameters under consideration for the uncertainty analysis were those that met both conditions (a) and (b), or only condition (c).

(a) Parameters of the exposure pathway, which account for more than 5% of the total additional exposure dose in any of the four age groups（See Tables 7-10）
(b) Averages and standard values.
(c) Parameters whose values change as a result of considering variations in parameters that match both conditions (a) and (b).

The parameters that match both conditions (a) and (b) were the external exposure time (t_s), the annual intake of food (M_f), and the market dilution factor of food (G_f). The parameters consistent with condition (c) were the soil ingestion time in former TSS ($t_{s,ing}$), the dust inhalation time in former TSS ($t_{s,inh}$) and the market dilution factor of feed(f_r). The list of parameters that were conservatively set to account for uncertainty is given in Tables 3-6. The method for setting each parameter considering the variations is as Appendix B.

Table 3. Parameters considered for uncertainty in each scenario (Adult)

Scenario	Parameters considered for uncertainty	Standard parameter values	Conservative parameter values
Paddy	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$)	183 h/year	640 h/year
	dust inhalation time in former TSS ($t_{s,inh}$)	53 h/year	186 h/year
	annual intake of food (M_f)	54 kgFW/year	98 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (vegetable)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	858 h/year	1,069 h/year
	annual intake of food (M_f)	102 kgFW/year	191 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (flower)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	852 h/year	989 h/year
Orchard	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	540 h/year	781 h/year
	annual intake of food (M_f)	37 kgFW/year	113 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Pasture (milk cow)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	1,244 h/year	2,284 h/year
	annual intake of food (M_f)	23 kgFW/year	70 kgFW/year
	market dilution factor of food (G_f)	0.5	1
	market dilution factor of feed (f_r)	0.12	0.18
Pasture (beef cattle)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	928 h/year	1,686 h/year
Managed Forest	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	313 h/year	313 h/year
Residence	external exposure time (indoor) (t_s)	5,778 h/year	8,618 h/year
Park	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	178 h/year	518 h/year

Table 4. Parameters considered for uncertainty in each scenario (1-6 years old)

Scenario	Parameters considered for uncertainty	Standard parameter values	Conservative parameter values
Paddy	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$)	183 h/year	640 h/year
	dust inhalation time in former TSS ($t_{s,inh}$)	53 h/year	186 h/year
	annual intake of food (M_f)	35 kgFW/year	51 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (vegetable)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	858 h/year	1,069 h/year
	annual intake of food (M_f)	47 kgFW/year	75 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (flower)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	852 h/year	989 h/year
Orchard	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	540 h/year	781 h/year
	annual intake of food (M_f)	34 kgFW/year	68 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Pasture (milk cow)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	1,244 h/year	2,284 h/year
	annual intake of food (M_f)	52 kgFW/year	107 kgFW/year
	market dilution factor of food (G_f)	0.5	1
	market dilution factor of feed (f_r)	0.12	0.18
Pasture (beef cattle)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	928 h/year	1,686 h/year
Managed Forest	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	313 h/year	313 h/year
Residence	external exposure time (indoor) (t_s)	6,998 h/year	8,618 h/year
Park	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	232 h/year	515 h/year

Table 5. Parameters considered for uncertainty in each scenario (7-14 years old)

Scenario	Parameters considered for uncertainty	Standard parameter values	Conservative parameter values
Paddy	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$)	183 h/year	640 h/year
	dust inhalation time in former TSS ($t_{s,inh}$)	53 h/year	186 h/year
	annual intake of food （M_f）	61 kgFW/year	92 kgFW/year
	market dilution factor of food （G_f）	0.5	1
Cropland (vegetable)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	858 h/year	1,069 h/year
	annual intake of food （M_f）	88 kgFW/year	133 kgFW/year
	market dilution factor of food （G_f）	0.5	1
Cropland (flower)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	852 h/year	989 h/year
Orchard	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	540 h/year	781 h/year
	annual intake of food （M_f）	27 kgFW/year	61 kgFW/year
	market dilution factor of food （G_f）	0.5	1
Pasture (milk cow)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	1,244 h/year	2,284 h/year
	annual intake of food （M_f）	92 kgFW/year	147 kgFW/year
	market dilution factor of food （G_f）	0.5	1
	market dilution factor of feed （f_r）	0.12	0.18
Pasture (beef cattle)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	928 h/year	1,686 h/year
Managed Forest	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	313 h/year	313 h/year
Residence	external exposure time (indoor) （t_s）	5,315 h/year	6,991 h/year
Park	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	217 h/year	593 h/year

Table 6. Parameters considered for uncertainty in each scenario (15-19 years old)

Scenario	Parameters considered for uncertainty	Standard parameter values	Conservative parameter values
Paddy	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$)	183 h/year	640 h/year
	dust inhalation time in former TSS ($t_{s,inh}$)	53 h/year	186 h/year
	annual intake of food (M_f)	78 kgFW/year	118 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (vegetable)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	858 h/year	1,069 h/year
	annual intake of food (M_f)	89 kgFW/year	145 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Cropland (flower)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	852 h/year	989 h/year
Orchard	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	540 h/year	781 h/year
	annual intake of food (M_f)	24 kgFW/year	64 kgFW/year
	market dilution factor of food (G_f)	0.5	1
Pasture (milk cow)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	1,244 h/year	2,284 h/year
	annual intake of food (M_f)	36 kgFW/year	88 kgFW/year
	market dilution factor of food (G_f)	0.5	1
	market dilution factor of feed (f_r)	0.12	0.18
Pasture (beef cattle)	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	928 h/year	1,686 h/year
Managed Forest	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	313 h/year	313 h/year
Residence	external exposure time (indoor) (t_s)	5,315 h/year	6,991 h/year
Park	external exposure time(t_s), soil ingestion time in former TSS ($t_{s,ing}$), dust inhalation time in former TSS ($t_{s,inh}$)	210 h/year	526 h/year

4. Assessment Result of additional exposure dose per unit concentration of radioactive cesium

4.1 Assessment results using average and standard parameter values

The calculation results of the additional exposure dose per unit concentration of the radioactive cesium in soil are shown in Tables 7 to 10. The calculated additional exposure doses were highest for the Residence scenario. The 1-6 years old age group received the highest exposure doses of 4.1×10^{-4} (mSv/year)/(Bq/kg).

For all scenarios other than the Paddy scenario, external exposure was the dominant contributor to total additional exposure dose. In the Residence scenario, the external exposure dose was larger than in the other scenarios due to the longer time spent at the TSS site (home time. In the Paddy scenario, since the time spent (working hours) at the former TSS was relatively short, the importance of the external exposure dose was relatively lower. The internal exposure doses due to the soil ingestion and the dust inhalation were small in all scenarios. The additional exposure dose in each exposure pathway was slightly different among the age groups, but the total values did not differ significantly.

Moreover, when conducting the additional exposure dose assessment in response to requests from municipalities and landowners of the TSSs, actual values should be applied not only for the concentration of radioactive cesium in the topsoil, but also for various parameters with respect to the potential usage time and food intake from the former TSS. As the result of this, more realistic assessment becomes possible. In this study, although the ratio between the cesium-134 and the cesium-137 was decided based on the ratio in June 2022, it is possible to consider an actual measurement day and change the existence ratio. However, since the existence ratio of cesium 134 is very small as of June 2022, it is considered that there is little effect even if it is changed in consideration of the actual measurement date in the future.

Table 7. Additional exposure dose per unit concentration of radioactive cesium in each scenario (Adults)

(mSv/year) / (Bq/kg)

Scenario	External exposure	Internal exposure (food ingestion)	Internal exposure (soil ingestion)	Internal exposure (dust inhalation)	Total
Paddy	1.9×10^{-5}	1.5×10^{-5}	2.1×10^{-9}	6.1×10^{-10}	3.4×10^{-5}
	56.9%	43.1%	0.0%	0.0%	100.0%
Cropland (vegetable)	9.1×10^{-5}	2.8×10^{-5}	9.7×10^{-9}	9.9×10^{-9}	1.2×10^{-4}
	76.6%	23.4%	0.0%	0.0%	100.0%
Cropland (flower)	9.1×10^{-5}	-	9.6×10^{-9}	9.8×10^{-9}	9.1×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Orchard	5.7×10^{-5}	9.9×10^{-6}	6.1×10^{-9}	6.2×10^{-9}	6.7×10^{-5}
	85.2%	14.7%	0.0%	0.0%	100.0%
Pasture (milk cow)	1.3×10^{-4}	3.0×10^{-6}	1.4×10^{-8}	1.4×10^{-8}	1.4×10^{-4}
	97.8%	2.2%	0.0%	0.0%	100.0%
Pasture (beef cattle)	9.9×10^{-5}	-	1.0×10^{-8}	1.1×10^{-8}	9.9×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Managed Forest	1.1×10^{-5}	-	2.7×10^{-11}	1.2×10^{-9}	1.1×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Residence	2.6×10^{-4}	6.4×10^{-6}	1.6×10^{-9}	1.6×10^{-9}	2.7×10^{-4}
	97.6%	2.4%	0.0%	0.0%	100.0%
Park	1.9×10^{-5}	-	2.0×10^{-9}	2.1×10^{-9}	1.9×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%

（The lower row shows the percentage of the total additional exposure dose.）

Table 8. Additional exposure dose per unit concentration of radioactive cesium in each scenario (1-6 years old)

(mSv/year) / (Bq/kg)

Scenario	External exposure	Internal exposure (food ingestion)	Internal exposure (soil ingestion)	Internal exposure (dust inhalation)	Total
Paddy	2.5×10^{-5}	8.7×10^{-6}	7.6×10^{-9}	7.2×10^{-10}	3.4×10^{-5}
	74.4%	25.6%	0.0%	0.0%	100.0%
Cropland (vegetable)	1.2×10^{-4}	1.2×10^{-5}	3.6×10^{-8}	1.2×10^{-8}	1.3×10^{-4}
	90.9%	9.0%	0.0%	0.0%	100.0%
Cropland (flower)	1.2×10^{-4}	-	3.5×10^{-8}	1.1×10^{-8}	1.2×10^{-4}
	100.0%	-	0.0%	0.0%	100.0%
Orchard	7.5×10^{-5}	8.5×10^{-6}	2.2×10^{-8}	7.3×10^{-9}	8.3×10^{-5}
	89.8%	10.2%	0.0%	0.0%	100.0%
Pasture (milk cow)	1.7×10^{-4}	6.4×10^{-6}	5.2×10^{-8}	1.7×10^{-8}	1.8×10^{-4}
	96.4%	3.6%	0.0%	0.0%	100.0%
Pasture (beef cattle)	1.3×10^{-4}	-	3.9×10^{-8}	1.3×10^{-8}	1.3×10^{-4}
	100.0%	-	0.0%	0.0%	100.0%
Managed Forest	1.4×10^{-5}	-	9.8×10^{-11}	1.4×10^{-9}	1.4×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Residence	4.1×10^{-4}	2.3×10^{-6}	5.9×10^{-9}	1.9×10^{-9}	4.1×10^{-4}
	99.4%	0.6%	0.0%	0.0%	100.0%
Park	3.3×10^{-5}	-	1.0×10^{-8}	3.2×10^{-9}	3.3×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%

(The lower row shows the percentage of the total additional exposure dose.)

Table 9. Additional exposure dose per unit concentration of radioactive cesium in each scenario (7-14 years old)

(mSv/year) / (Bq/kg)

Scenario	External exposure	Internal exposure (food ingestion)	Internal exposure (soil ingestion)	Internal exposure (dust inhalation)	Total
Paddy	2.1×10^{-5}	1.3×10^{-5}	4.8×10^{-9}	4.9×10^{-10}	3.4×10^{-5}
	62.9%	37.0%	0.0%	0.0%	100.0%
Cropland (vegetable)	1.0×10^{-4}	1.8×10^{-5}	2.2×10^{-8}	7.9×10^{-9}	1.2×10^{-4}
	84.6%	15.4%	0.0%	0.0%	100.0%
Cropland (flower)	1.0×10^{-4}	-	2.2×10^{-8}	7.9×10^{-9}	1.0×10^{-4}
	100.0%	-	0.0%	0.0%	100.0%
Orchard	6.3×10^{-5}	5.6×10^{-6}	1.4×10^{-8}	5.0×10^{-9}	6.9×10^{-5}
	91.8%	8.1%	0.0%	0.0%	100.0%
Pasture (milk cow)	1.5×10^{-4}	9.4×10^{-6}	3.2×10^{-8}	1.2×10^{-8}	1.6×10^{-4}
	93.9%	6.0%	0.0%	0.0%	100.0%
Pasture (beef cattle)	1.1×10^{-4}	-	2.4×10^{-8}	8.6×10^{-9}	1.1×10^{-4}
	100.0%	-	0.0%	0.0%	100.0%
Managed Forest	1.2×10^{-5}	-	6.1×10^{-11}	9.9×10^{-10}	1.2×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Residence	2.6×10^{-4}	3.7×10^{-6}	2.2×10^{-9}	1.3×10^{-9}	2.6×10^{-4}
	98.6%	1.4%	0.0%	0.0%	100.0%
Park	2.6×10^{-5}	-	5.7×10^{-9}	2.0×10^{-9}	2.6×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%

(The lower row shows the percentage of the total additional exposure dose.)

Table 10. Additional exposure dose per unit concentration of radioactive cesium in each scenario (15-19 years old)

(mSv/year) / (Bq/kg)

Scenario	External exposure	Internal exposure (food ingestion)	Internal exposure (soil ingestion)	Internal exposure (dust inhalation)	Total
Paddy	2.0×10^{-5}	2.1×10^{-5}	2.1×10^{-9}	5.8×10^{-10}	4.1×10^{-5}
	48.5%	51.5%	0.0%	0.0%	100.0%
Cropland (vegetable)	9.3×10^{-5}	2.4×10^{-5}	9.7×10^{-9}	9.4×10^{-9}	1.2×10^{-4}
	79.5%	20.5%	0.0%	0.0%	100.0%
Cropland (flower)	9.3×10^{-5}	-	9.6×10^{-9}	9.4×10^{-9}	9.3×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Orchard	5.9×10^{-5}	6.6×10^{-6}	6.1×10^{-9}	5.9×10^{-9}	6.5×10^{-5}
	89.9%	10.0%	0.0%	0.0%	100.0%
Pasture (milk cow)	1.4×10^{-4}	4.8×10-^{6}	1.4×10^{-8}	1.4×10^{-8}	1.4×10^{-4}
	96.5%	3.4%	0.0%	0.0%	100.0%
Pasture (beef cattle)	1.0×10^{-4}	-	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-4}
	100.0%	-	0.0%	0.0%	100.0%
Managed Forest	1.1×10^{-5}	-	2.7×10^{-11}	1.2×10^{-9}	1.1×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%
Residence	2.4×10^{-4}	4.8×10^{-6}	9.6×10^{-10}	1.6×10^{-9}	2.5×10^{-4}
	98.0%	2.0%	0.0%	0.0%	100.0%
Park	2.3×10^{-5}	-	2.4×10^{-9}	2.3×10^{-9}	2.3×10^{-5}
	100.0%	-	0.0%	0.0%	100.0%

(The lower row shows the percentage of the total additional exposure dose.)

4.2. Result of uncertainty analysis

In order to analyze the effect of the uncertainty in the parameter values, the additional exposure doses per unit concentration of radioactive cesium were calculated using conservative values, and the results are shown in Tables 11-14. The calculated additional exposure doses were highest for the Residence scenario. The 1-6 years old age group received the highest exposure doses of 5.0×10^{-4} (mSv/year)/(Bq/kg). Comparing the calculated total dose results using the conservative parameters with those calculated using the average or standard values, it was found that the increase in the additional exposure dose was up to a factor of 3.6 times greater in the Paddy scenario for adults. The ratio of the calculated dose using the average or standard parameter values to the calculated dose using the conservative parameter values did not differ greatly depending on the age group. Note that in the Managed Forest scenario, all parameters in the standard and conservative calculation methods have the same values.

Table 11. Results of the uncertainty analysis of parameter values (Adult)

（mSv/year）/（Bq/kg）

Scenario	Calculation method	External exposure	Internal exposure	Total	Ratio Conservative total dose/Standard total dose
Paddy	Standard	1.9×10^{-5}	1.5×10^{-5}	3.4×10^{-5}	3.6
	Conservative	6.8×10^{-5}	5.3×10^{-5}	1.2×10^{-4}	
Cropland (vegetable)	Standard	9.1×10^{-5}	2.8×10^{-5}	1.2×10^{-4}	1.8
	Conservative	1.1×10^{-4}	1.0×10^{-4}	2.2×10^{-4}	
Cropland (flower)	Standard	9.1×10^{-5}	1.9×10^{-8}	9.1×10^{-5}	1.2
	Conservative	1.1×10^{-4}	2.3×10^{-8}	1.1×10^{-4}	
Orchard	Standard	5.7×10^{-5}	9.9×10^{-6}	6.7×10^{-5}	2.1
	Conservative	8.3×10^{-5}	6.2×10^{-5}	1.4×10^{-4}	
Pasture (milk cow)	Standard	1.3×10^{-4}	3.0×10^{-6}	1.4×10^{-4}	2.0
	Conservative	2.4×10^{-4}	2.7×10^{-5}	2.7×10^{-4}	
Pasture (beef cattle)	Standard	9.9×10^{-5}	2.1×10^{-8}	9.9×10^{-5}	1.8
	Conservative	1.8×10^{-4}	3.8×10^{-8}	1.8×10^{-4}	
Managed Forest	Standard	1.1×10^{-5}	1.3×10^{-9}	1.1×10^{-5}	1.0
	Conservative	1.1×10^{-5}	1.3×10^{-9}	1.1×10^{-5}	
Residence	Standard	2.6×10^{-4}	6.4×10^{-6}	2.7×10^{-4}	1.5
	Conservative	3.8×10^{-4}	6.4×10^{-6}	3.9×10^{-4}	
Park	Standard	1.9×10^{-5}	4.1×10^{-9}	1.9×10^{-5}	2.9
	Conservative	5.5×10^{-5}	1.2×10^{-8}	5.5×10^{-5}	

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 12. Results of the uncertainty analysis of parameter values (1-6 years old)

（mSv/year）/（Bq/kg）

Scenario	Calculation method	External exposure	Internal exposure	Total	Ratio Conservative total dose/Standard total dose
Paddy	Standard	2.5×10^{-5}	8.7×10^{-6}	3.4×10^{-5}	3.4
	Conservative	8.8×10^{-5}	2.6×10^{-5}	1.1×10^{-4}	
Cropland (vegetable)	Standard	1.2×10^{-4}	1.2×10^{-5}	1.3×10^{-4}	1.4
	Conservative	1.5×10^{-4}	3.7×10^{-5}	1.9×10^{-4}	
Cropland (flower)	Standard	1.2×10^{-4}	4.7×10^{-8}	1.2×10^{-4}	1.2
	Conservative	1.4×10^{-4}	5.4×10^{-8}	1.4×10^{-4}	
Orchard	Standard	7.5×10^{-5}	8.5×10^{-6}	8.3×10^{-5}	1.7
	Conservative	1.1×10^{-4}	3.4×10^{-5}	1.4×10^{-4}	
Pasture (milk cow)	Standard	1.7×10^{-4}	6.5×10^{-6}	1.8×10^{-4}	2.0
	Conservative	3.2×10^{-4}	3.8×10^{-5}	3.5×10^{-4}	
Pasture (beef cattle)	Standard	1.3×10^{-4}	5.1×10^{-8}	1.3×10^{-4}	1.8
	Conservative	2.3×10^{-4}	9.3×10^{-8}	2.3×10^{-4}	
Managed Forest	Standard	1.4×10^{-5}	1.5×10^{-9}	1.4×10^{-5}	1.0
	Conservative	1.4×10^{-5}	1.5×10^{-9}	1.4×10^{-5}	
Residence	Standard	4.1×10^{-4}	2.4×10^{-6}	4.1×10^{-4}	1.2
	Conservative	5.0×10^{-4}	2.4×10^{-6}	5.0×10^{-4}	
Park	Standard	3.3×10^{-5}	1.3×10^{-8}	3.3×10^{-5}	2.2
	Conservative	7.2×10^{-5}	2.9×10^{-8}	7.2×10^{-5}	

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 13. Results of the uncertainty analysis of parameter values (7-14 years old)

(mSv/year) / (Bq/kg)

Scenario	Calculation method	External exposure	Internal exposure	Total	Ratio Conservative total dose/Standard total dose
Paddy	Standard	2.1×10^{-5}	1.3×10^{-5}	3.4×10^{-5}	3.3
	Conservative	7.5×10^{-5}	3.8×10^{-5}	1.1×10^{-4}	
Cropland (vegetable)	Standard	1.0×10^{-4}	1.8×10^{-5}	1.2×10^{-4}	1.5
	Conservative	1.3×10^{-4}	5.6×10^{-5}	1.8×10^{-4}	
Cropland (flower)	Standard	1.0×10^{-4}	3.0×10^{-8}	1.0×10^{-4}	1.2
	Conservative	1.2×10^{-4}	3.5×10^{-8}	1.2×10^{-4}	
Orchard	Standard	6.3×10^{-5}	5.6×10^{-6}	6.9×10^{-5}	1.7
	Conservative	9.2×10^{-5}	2.5×10^{-5}	1.2×10^{-4}	
Pasture (milk cow)	Standard	1.5×10^{-4}	9.4×10^{-6}	1.6×10^{-4}	2.0
	Conservative	2.7×10^{-4}	4.4×10^{-5}	3.1×10^{-4}	
Pasture (beef cattle)	Standard	1.1×10^{-4}	3.3×10^{-8}	1.1×10^{-4}	1.8
	Conservative	2.0×10^{-4}	6.0×10^{-8}	2.0×10^{-4}	
Managed Forest	Standard	1.2×10^{-5}	1.0×10^{-9}	1.2×10^{-5}	1.0
	Conservative	1.2×10^{-5}	1.0×10^{-9}	1.2×10^{-5}	
Residence	Standard	2.6×10^{-4}	3.7×10^{-6}	2.6×10^{-4}	1.3
	Conservative	3.4×10^{-4}	3.7×10^{-6}	3.4×10^{-4}	
Park	Standard	2.6×10^{-5}	7.8×10^{-9}	2.6×10^{-5}	2.7
	Conservative	7.1×10^{-5}	2.1×10^{-8}	7.1×10^{-5}	

(In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".)

Table 14. Results of the uncertainty analysis of parameter values (15-19 years old)

（mSv/year）/（Bq/kg）

Scenario	Calculation method	External exposure	Internal exposure	Total	Ratio Conservative total dose/Standard total dose
Paddy	Standard	2.0×10^{-5}	2.1×10^{-5}	4.1×10^{-5}	3.3
	Conservative	7.0×10^{-5}	6.4×10^{-5}	1.3×10^{-4}	
Cropland (vegetable)	Standard	9.3×10^{-5}	2.4×10^{-5}	1.2×10^{-4}	1.7
	Conservative	1.2×10^{-4}	7.9×10^{-5}	2.0×10^{-4}	
Cropland (flower)	Standard	9.3×10^{-5}	1.9×10^{-8}	9.3×10^{-5}	1.2
	Conservative	1.1×10^{-4}	2.2×10^{-8}	1.1×10^{-4}	
Orchard	Standard	5.9×10^{-5}	6.6×10^{-6}	6.5×10^{-5}	1.8
	Conservative	8.5×10^{-5}	3.5×10^{-5}	1.2×10^{-4}	
Pasture (milk cow)	Standard	1.4×10^{-4}	4.9×10^{-6}	1.4×10^{-4}	2.0
	Conservative	2.5×10^{-4}	3.4×10^{-5}	2.8×10^{-4}	
Pasture (beef cattle)	Standard	1.0×10^{-4}	2.1×10^{-8}	1.0×10^{-4}	1.8
	Conservative	1.8×10^{-4}	3.8×10^{-8}	1.8×10^{-4}	
Managed Forest	Standard	1.1×10^{-5}	1.2×10^{-9}	1.1×10^{-5}	1.0
	Conservative	1.1×10^{-5}	1.2×10^{-9}	1.1×10^{-5}	
Residence	Standard	2.4×10^{-4}	4.8×10^{-6}	2.5×10^{-4}	1.3
	Conservative	3.1×10^{-4}	4.8×10^{-6}	3.2×10^{-4}	
Park	Standard	2.3×10^{-5}	4.7×10^{-9}	2.3×10^{-5}	2.5
	Conservative	5.8×10^{-5}	1.2×10^{-8}	5.8×10^{-5}	

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

5. Methods for Case Studies

The additional exposure dose per unit concentration of radioactive cesium (mSv/year)/(Bq/kg) calculated in 3.4 was multiplied by "the cesium concentration in the topsoil of the former TSS" or "the cesium concentration estimated from the air dose rate of the former TSS," and the additional exposure dose (mSv/year) was assessed as the case studies. Furthermore, we compared the calculated additional exposure dose with the long-term goal (1 mSv/year).

5.1. Assessment method of additional exposure dose by using the actual radioactive cesium concentration measured at the former TSS.

Case study calculations were done by multiplying the standard additional exposure dose per unit concentration of radioactive cesium shown in 3.4.1 and the conservative additional exposure dose per unit concentration of radioactive cesium shown in 3.4.2 by the measured values of cesium-137 concentration in the topsoil of the actual former TSS. In the standard case assessment, the average value of the measured values was used. In the conservative case assessment, the maximum value of the measured value was used. The measured values of radioactive cesium concentration in the topsoil of the former TSSs used for the calculation are shown in Table 15. In order to assess the former TSSs in various situations, the TSSs of the three areas, A, B and C, were selected, which differ in their assumed land-use and areas where they are located. For the assumed land-use, interviews were conducted with the municipalities where the former TSSs are located. Although the date of measurement of radioactive cesium concentration at each TSS is different, all values were assessed as of June 2022.

Soil sampling was done within 5 cm depth from the surface. Soil sampling points for the TSS of A were selected by dividing the entire TSS into three subdivisions so that each subdivision was no larger than 1,000 m^2. Five points were selected at the center and four corners of each subdivision. The soil sampling points for the TSSs of B and C were the same some areas where the soil was stored. If the area of the plot where the soil was stored did not exceed 20 m x 20 m, the center and four corners of the TSS were used as soil sampling points. If the area exceeded 20 m x 20 m, the plot was divided into meshes of about 10 m in addition to the center and four corners, and the center and four corners of each mesh were used as soil sampling points. The concentration of cesium-137 in the soil was measured with a germanium semiconductor detector. The selection of soil sampling sites described above differs from the method in the Ministry of the Environment's guidelines [2].

The concentration of cesium-137 in the topsoil of the TSS of A was higher than that of the TSS of B or C (Table 15). The very low Cs-137 concentrations in TSS B and C are probably due to these sites being levelled before the TSS was created.

Table 15. Basic information and measurement results of the former temporary storage site where actual measurement of cesium-137 concentration in soil was conducted

	Assumed land-use	Area size [m^2]	Number of sites where soil samples were taken	concentration of ^{137}Cs [Bq/kg] maximum	concentration of ^{137}Cs [Bq/kg] average	Location Area
TSS A	Agricultural land (excluding pasture)	2.3×10^3	11	636	160	Hamadori
TSS B	Managed Forest	7.5×10^3	400	38	6	Nakadori
TSS C	Buildings, parks, etc.	1.0×10^3	38	13	4	Aizu

（The mean value was calculated by excluding values below the detection limit.）

5.2 Assessment method of additional exposure dose using measured value of air dose rate in TSS

In order to confirm the representativeness of the case studies described in section 5.1, questionnaire surveys were carried out for 29 municipalities (including the sites of 794 TSSs) from among the municipalities in ICSA in Fukushima Prefecture. As a result, values of the air dose rate at a large number of TSS were obtained.

The survey period was from February 16th to March 31th, 2022. The survey items are the measurement date and the air dose rate at the position of 1 m height from the ground of the TSS measured by the municipality after the restoration work was completed (the measurement result of (5) in Figure 6). However, if the municipality did not measure air dose rates after the restoration work was completed, air dose rates after the removal of the removed soil (the measurement result of (3) in Figure 6) were answered instead. Many municipalities use the air dose rates instead of the radioactive cesium concentrations in the topsoil to determine the presence or absence of contamination. When the measurement lasted several days, the data from the last day was used. In cases where the measurement date at a certain TSS was unknown, the most recent data available from other TSS sites in the same municipality were used.

The probability distribution of the additional exposure dose for the survey sites was estimated by multiplying the cesium 137 concentration in the surface soil converted from the air dose rate of each TSS site by the additional exposure dose per unit concentration of the radioactive cesium calculated in Section 3.4. Equations (C1) and (C2) in Appendix C were used to convert air dose rates to cesium 137 concentrations in topsoil. The estimated probability distribution for the survey sites was compared with the results for the case studies in Section 5.1.

6. Assessed Results of Case Studies

6.1. Assessed Results of additional exposure dose calculated from the measured radioactive cesium concentration in three actual TSSs

The calculation results for the additional exposure dose using the cesium-137 concentration measured in the topsoil of the actual TSSs are shown in Tables 16-19.

- In the calculations using the average and standard parameter values, the greatest additional exposure dose, 2.1×10^{-2} mSv/year, was calculated for TSS A for the Cropland (vegetable) scenario and the 1-6 years old age group.
- In the calculations using the conservative parameter values, the greatest additional exposure dose, 1.4×10^{-1} mSv/year, was calculated for TSS A for the Cropland (vegetable) scenario and adults.

As these values are below 1 mSv/year, the sites of TSS A, B and C can be used safely. Other former TSS sites having the same or lower concentrations of radioactive Cs and the same land uses as TSS sites A, B and C should also be safe.

Table 16. Additional exposure dose by using cesium-137 concentration in the topsoil of the actual former TSS (Adult)

(mSv/year)

TSS	Scenario	Calculation method	External exposure	Internal exposure	Total
TSS A	Paddy	Standard	3.1×10^{-3}	2.4×10^{-3}	5.5×10^{-3}
		Conservative	4.3×10^{-2}	3.4×10^{-2}	7.7×10^{-2}
	Cropland (vegetable)	Standard	1.5×10^{-2}	4.5×10^{-3}	1.9×10^{-2}
		Conservative	7.2×10^{-2}	6.6×10^{-2}	1.4×10^{-1}
	Cropland (flower)	Standard	1.5×10^{-2}	3.1×10^{-6}	1.5×10^{-2}
		Conservative	6.7×10^{-2}	1.4×10^{-5}	6.7×10^{-2}
	Orchard	Standard	9.2×10^{-3}	1.6×10^{-3}	1.1×10^{-2}
		Conservative	5.3×10^{-2}	3.9×10^{-2}	9.2×10^{-2}
TSS B	Managed Forest	Standard	7.3×10^{-5}	8.4×10^{-9}	7.3×10^{-5}
		Conservative	4.2×10^{-4}	4.8×10^{-8}	4.2×10^{-4}
TSS C	Residence	Standard	1.6×10^{-3}	3.8×10^{-5}	1.6×10^{-3}
		Conservative	4.9×10^{-3}	8.3×10^{-5}	5.0×10^{-3}
	Park	Standard	1.1×10^{-4}	2.5×10^{-8}	1.1×10^{-4}
		Conservative	7.1×10^{-4}	1.5×10^{-7}	7.1×10^{-4}

(In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".)

Table 17. Additional exposure dose by using cesium-137 concentration in the topsoil of the actual former TSS (1-6 years old)

（mSv/year）

TSS	Scenario	Calculation method	External exposure	Internal exposure	Total
TSS A	Paddy	Standard	4.0×10^{-3}	1.4×10^{-3}	5.4×10^{-3}
		Conservative	5.6×10^{-2}	1.6×10^{-2}	7.3×10^{-2}
	Cropland (vegetable)	Standard	1.9×10^{-2}	1.9×10^{-3}	2.1×10^{-2}
		Conservative	9.4×10^{-2}	2.4×10^{-2}	1.2×10^{-1}
	Cropland (flower)	Standard	1.9×10^{-2}	7.5×10^{-6}	1.9×10^{-2}
		Conservative	8.7×10^{-2}	3.5×10^{-5}	8.7×10^{-2}
	Orchard	Standard	1.2×10^{-2}	1.4×10^{-3}	1.3×10^{-2}
		Conservative	6.9×10^{-2}	2.1×10^{-2}	9.0×10^{-2}
TSS B	Managed Forest	Standard	9.5×10^{-5}	1.0×10^{-8}	9.5×10^{-5}
		Conservative	5.5×10^{-4}	5.9×10^{-8}	5.5×10^{-4}
TSS C	Residence	Standard	2.4×10^{-3}	1.4×10^{-5}	2.5×10^{-3}
		Conservative	6.4×10^{-3}	3.0×10^{-5}	6.4×10^{-3}
	Park	Standard	2.0×10^{-4}	7.9×10^{-8}	2.0×10^{-4}
		Conservative	9.3×10^{-4}	3.7×10^{-7}	9.3×10^{-4}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 18. Additional exposure dose by using cesium-137 concentration in the topsoil of the actual former TSS (7-14 years old)

（mSv/year）

TSS	Scenario	Calculation method	External exposure	Internal exposure	Total
TSS A	Paddy	Standard	3.4×10^{-3}	2.0×10^{-3}	5.5×10^{-3}
		Conservative	4.8×10^{-2}	2.4×10^{-2}	7.2×10^{-2}
	Cropland (vegetable)	Standard	1.6×10^{-2}	2.9×10^{-3}	1.9×10^{-2}
		Conservative	8.0×10^{-2}	3.5×10^{-2}	1.2×10^{-1}
	Cropland (flower)	Standard	1.6×10^{-2}	4.8×10^{-6}	1.6×10^{-2}
		Conservative	7.4×10^{-2}	2.2×10^{-5}	7.4×10^{-2}
	Orchard	Standard	1.0×10^{-2}	9.0×10^{-4}	1.1×10^{-2}
		Conservative	5.8×10^{-2}	1.6×10^{-2}	7.4×10^{-2}
TSS B	Managed Forest	Standard	8.1×10^{-5}	7.0×10^{-9}	8.1×10^{-5}
		Conservative	4.6×10^{-4}	4.0×10^{-8}	4.6×10^{-4}
TSS C	Residence	Standard	1.6×10^{-3}	2.2×10^{-5}	1.6×10^{-3}
		Conservative	4.4×10^{-3}	4.7×10^{-5}	4.4×10^{-3}
	Park	Standard	1.6×10^{-4}	4.7×10^{-8}	1.6×10^{-4}
		Conservative	9.1×10^{-4}	2.7×10^{-7}	9.1×10^{-4}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 19. Additional exposure dose by using cesium-137 concentration in the topsoil of the actual former TSS (15-19 years old)

（mSv/year）

TSS	Scenario	Calculation method	External exposure	Internal exposure	Total
TSS A	Paddy	Standard	3.2×10^{-3}	3.4×10^{-3}	6.6×10^{-3}
		Conservative	4.4×10^{-2}	4.1×10^{-2}	8.5×10^{-2}
	Cropland (vegetable)	Standard	1.5×10^{-2}	3.9×10^{-3}	1.9×10^{-2}
		Conservative	7.4×10^{-2}	5.0×10^{-2}	1.2×10^{-1}
	Cropland (flower)	Standard	1.5×10^{-2}	3.0×10^{-6}	1.5×10^{-2}
		Conservative	6.8×10^{-2}	1.4×10^{-5}	6.8×10^{-2}
	Orchard	Standard	9.4×10^{-3}	1.1×10^{-3}	1.0×10^{-2}
		Conservative	5.4×10^{-2}	2.2×10^{-2}	7.6×10^{-2}
TSS B	Managed Forest	Standard	7.5×10^{-5}	8.0×10^{-9}	7.5×10^{-5}
		Conservative	4.3×10^{-4}	4.6×10^{-8}	4.3×10^{-4}
TSS C	Residence	Standard	1.4×10^{-3}	2.9×10^{-5}	1.5×10^{-3}
		Conservative	4.0×10^{-3}	6.2×10^{-5}	4.1×10^{-3}
	Park	Standard	1.4×10^{-4}	2.8×10^{-8}	1.4×10^{-4}
		Conservative	7.4×10^{-4}	1.5×10^{-7}	7.4×10^{-4}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

6.2. Assessment results of additional exposure dose using measured value of air dose rate in site of TSS

As a result of the questionnaire to municipalities, 23 municipalities responded, and the values of the air dose rate (the measurement result of (5) in Figure 6) at the sites of 571 former TSSs were obtained. Of these 571, measurements were carried out just after the removal of soil at the sites of 138 former TSSs (the measurement result of (3) in Figure 6). The average and maximum values (minus the air dose rate based on the natural nuclides) of the measured air dose rates were 0.07 μSv/h and 0.31 μSv/h, respectively. The probability distribution of the air dose rates at the TSS is shown in Figure 9.

The concentration of cesium-137 in the topsoil was estimated from the air dose rates in the 571 former TSSs using equations (C1) and (C2) in Appendix C, and the estimated average value was 353 Bq/kg and the estimated maximum value was 1,434 Bq/kg. The additional exposure dose at each site was calculated from the estimated cesium-137 concentration, as follows:

- In the calculations using the average and standard parameter values (cesium-137 concentration is the average value), the expectation value of additional exposure dose, 9.4×10^{-2} mSv/year, was calculated for the Residence scenario and the adult.
- In the calculations using the average and standard parameter values (cesium-137 concentration is the maximum value), the greatest additional exposure dose, 5.9×10^{-1} mSv/year, was calculated for the Residence scenario and the 1-6 years old age group.
- In the calculations using the conservative parameter values (cesium-137 concentration is the maximum value), the greatest additional exposure dose, 7.1×10^{-1} mSv/year, was for the Residence scenario and the 1-6 years old age group.

The average and maximum values of the additional exposure dose for each age group in each site after TSS are shown in Tables 20-23.

The probability distribution of the additional exposure dose for adults is shown in Figures 10-18. This shows the probability distribution using standard parameters and the probability distribution conservative parameter values. The results for TSS A, B and C have also been added to the figures. In the distribution of the additional exposure dose estimated from the survey air dose rates, it was found that the TSS A is located on the higher dose range side from near the center, and conversely, the TSS B and C are located on the lower dose range side.

The average of the measured air dose rate (minus the air dose rate based on the natural nuclides) at TSS A was 0.06 μSv/h, and the cesium-137 concentration in the topsoil estimated using this value was 313 Bq/kg. The average of the measured cesium-137 concentration in the topsoil at TSS A was 160 Bq/kg, and the estimated value was about twice the measured value. This suggests that the calculations using equations (C1) and (C2) are conservative.

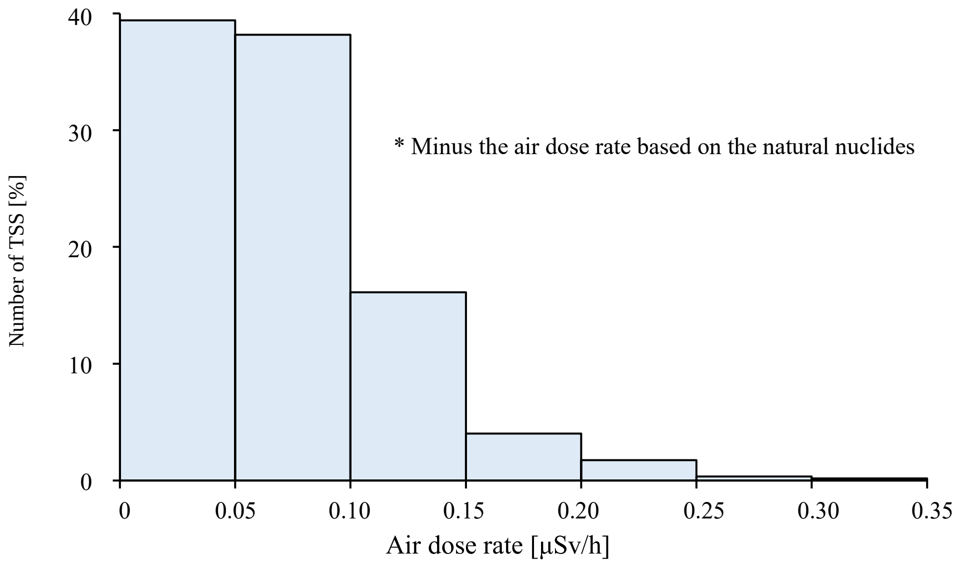


Figure 9. The probability distribution of the measured air dose rates at the TSS

Table 20. Additional exposure dose (adults) using cesium-137 concentration estimated from air dose rate

(mSv/year)

Scenario	Calculation method	Estimated cesium-137 concentration Average (353 Bq/kg)	Maximum (1,434 Bq/kg)
Paddy	Standard	1.2×10^{-2}	4.9×10^{-2}
	Conservative	4.3×10^{-2}	1.7×10^{-1}
Cropland (vegetable)	Standard	4.2×10^{-2}	1.7×10^{-1}
	Conservative	7.7×10^{-2}	3.1×10^{-1}
Cropland (flower)	Standard	3.2×10^{-2}	1.3×10^{-1}
	Conservative	3.7×10^{-2}	1.5×10^{-1}
Orchard	Standard	2.4×10^{-2}	9.7×10^{-2}
	Conservative	5.1×10^{-2}	2.1×10^{-1}
Pasture (milk cow)	Standard	4.8×10^{-2}	1.9×10^{-1}
	Conservative	9.5×10^{-2}	3.9×10^{-1}
Pasture (beef cattle)	Standard	3.5×10^{-2}	1.4×10^{-1}
	Conservative	6.3×10^{-2}	2.6×10^{-1}
Managed Forest	Standard	3.9×10^{-2}	1.6×10^{-2}
	Conservative	3.9×10^{-2}	1.6×10^{-2}
Residence	Standard	9.4×10^{-2}	3.8×10^{-1}
	Conservative	1.4×10^{-2}	5.6×10^{-1}
Park	Standard	6.8×10^{-2}	2.7×10^{-2}
	Conservative	2.0×10^{-2}	7.9×10^{-2}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 21. Additional exposure dose (1-6 years old) using cesium-137 concentration estimated from air dose rate

(mSv/year)

Scenario	Calculation method	Estimated cesium-137 concentration Average (353 Bq/kg)	Maximum (1,434 Bq/kg)
Paddy	Standard	1.2×10^{-2}	4.9×10^{-2}
	Conservative	4.0×10^{-2}	1.6×10^{-1}
Cropland (vegetable)	Standard	4.6×10^{-2}	1.9×10^{-1}
	Conservative	6.5×10^{-2}	2.7×10^{-1}
Cropland (flower)	Standard	4.2×10^{-2}	1.7×10^{-1}
	Conservative	4.8×10^{-2}	2.0×10^{-1}
Orchard	Standard	2.9×10^{-2}	1.2×10^{-1}
	Conservative	5.0×10^{-2}	2.0×10^{-1}
Pasture (milk cow)	Standard	6.3×10^{-2}	2.6×10^{-1}
	Conservative	1.3×10^{-1}	5.1×10^{-1}
Pasture (beef cattle)	Standard	4.5×10^{-2}	1.8×10^{-1}
	Conservative	8.2×10^{-2}	3.3×10^{-1}
Managed Forest	Standard	5.0×10^{-3}	2.0×10^{-2}
	Conservative	5.0×10^{-3}	2.0×10^{-2}
Residence	Standard	1.4×10^{-1}	5.9×10^{-1}
	Conservative	1.8×10^{-1}	7.1×10^{-1}
Park	Standard	1.2×10^{-2}	4.8×10^{-2}
	Conservative	2.5×10^{-2}	1.0×10^{-1}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 22. Additional exposure dose (7-14 years old) using cesium-137 concentration estimated from air dose rate

(mSv/year)

Scenario	Calculation method	Estimated cesium-137 concentration Average (353 Bq/kg)	Maximum (1,434 Bq/kg)
Paddy	Standard	1.2×10^{-2}	4.9×10^{-2}
	Conservative	4.0×10^{-2}	1.6×10^{-1}
Cropland (vegetable)	Standard	4.2×10^{-2}	1.7×10^{-1}
	Conservative	6.4×10^{-2}	2.6×10^{-1}
Cropland (flower)	Standard	3.5×10^{-2}	1.4×10^{-1}
	Conservative	4.1×10^{-2}	1.7×10^{-1}
Orchard	Standard	2.4×10^{-2}	9.9×10^{-2}
	Conservative	4.1×10^{-2}	1.7×10^{-1}
Pasture (milk cow)	Standard	5.5×10^{-2}	2.2×10^{-1}
	Conservative	1.1×10^{-1}	4.5×10^{-1}
Pasture (beef cattle)	Standard	3.9×10^{-2}	1.6×10^{-1}
	Conservative	7.0×10^{-2}	2.8×10^{-1}
Managed Forest	Standard	4.3×10^{-3}	1.7×10^{-2}
	Conservative	4.3×10^{-3}	1.7×10^{-2}
Residence	Standard	9.3×10^{-2}	3.8×10^{-1}
	Conservative	1.2×10^{-1}	4.9×10^{-1}
Park	Standard	9.1×10^{-3}	3.7×10^{-2}
	Conservative	2.5×10^{-2}	1.0×10^{-1}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

Table 23. Additional exposure dose (15-19 years old) using cesium-137 concentration estimated from air dose rate

(mSv/year)

Scenario	Calculation method	Estimated cesium-137 concentration Average (353 Bq/kg)	Maximum (1,434 Bq/kg)
Paddy	Standard	1.5×10^{-2}	5.9×10^{-2}
	Conservative	4.7×10^{-2}	1.9×10^{-1}
Cropland (vegetable)	Standard	4.1×10^{-2}	1.7×10^{-1}
	Conservative	6.9×10^{-2}	2.8×10^{-1}
Cropland (flower)	Standard	3.3×10^{-2}	1.3×10^{-1}
	Conservative	3.8×10^{-2}	1.5×10^{-1}
Orchard	Standard	2.3×10^{-2}	9.4×10^{-2}
	Conservative	4.2×10^{-2}	1.7×10^{-1}
Pasture (milk cow)	Standard	5.0×10^{-2}	2.0×10^{-1}
	Conservative	1.0×10^{-1}	4.1×10^{-1}
Pasture (beef cattle)	Standard	3.6×10^{-2}	1.4×10^{-1}
	Conservative	6.5×10^{-2}	2.6×10^{-1}
Managed Forest	Standard	4.0×10^{-3}	1.6×10^{-2}
	Conservative	4.0×10^{-3}	1.6×10^{-2}
Residence	Standard	8.7×10^{-2}	3.5×10^{-1}
	Conservative	1.1×10^{-1}	4.6×10^{-1}
Park	Standard	8.1×10^{-3}	3.3×10^{-2}
	Conservative	2.0×10^{-2}	8.3×10^{-2}

（In terms of calculation methods, calculations using average or standard parameter values were designated as "standard", while calculations using parameter values that take variability into account were designated as "conservative".）

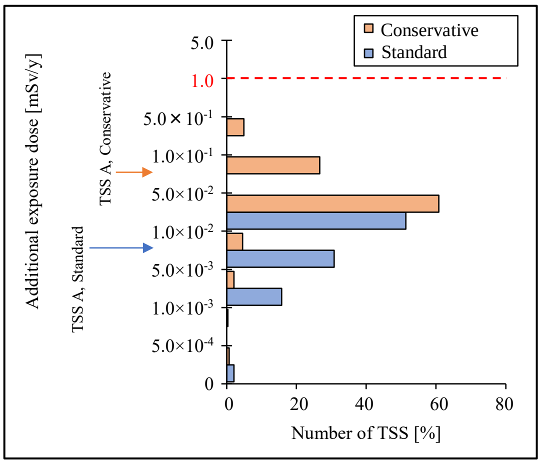


Figure 10. Additional exposure dose using estimated ^{137}Cs (Paddy scenario (Adult))

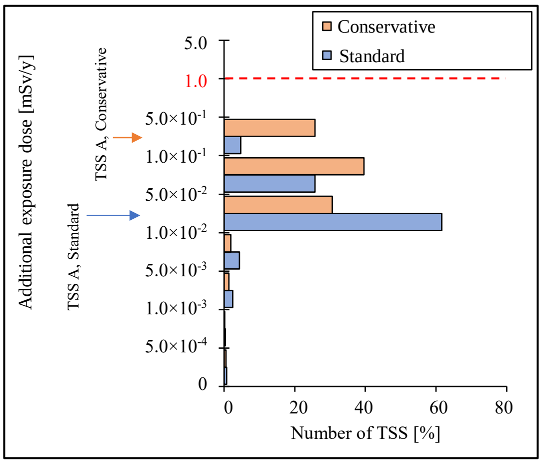


Figure 11. Additional exposure dose using estimated ^{137}Cs (Cropland (vegetable) scenario (Adult))

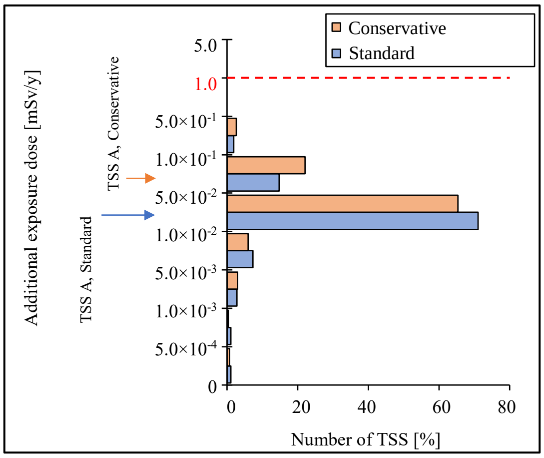


Figure 12. Additional exposure dose using estimated ^{137}Cs (Cropland (flower) scenario (Adult))

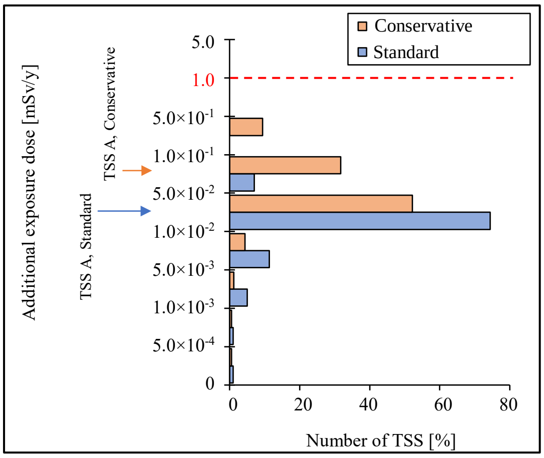


Figure 13. Additional exposure dose using estimated ^{137}Cs (Orchard scenario (Adult))

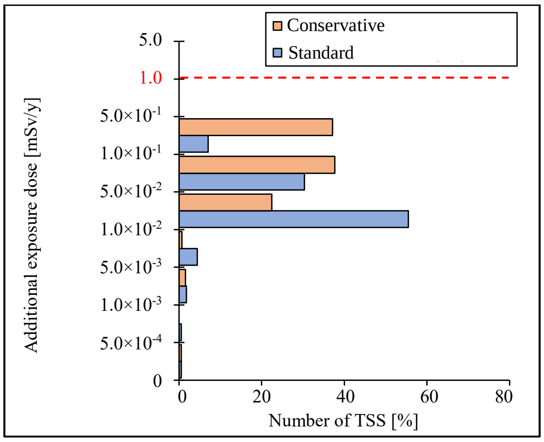


Figure 14. Additional exposure dose using estimated ^{137}Cs (Pasture (milk cow) scenario (Adult))

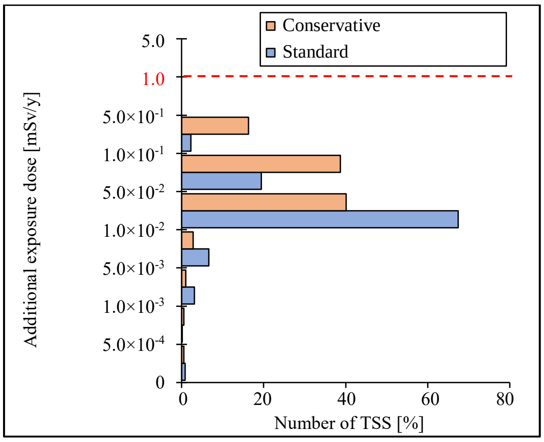


Figure 15. Additional exposure dose using estimated ^{137}Cs (Pasture (beef cattle) scenario (Adult))

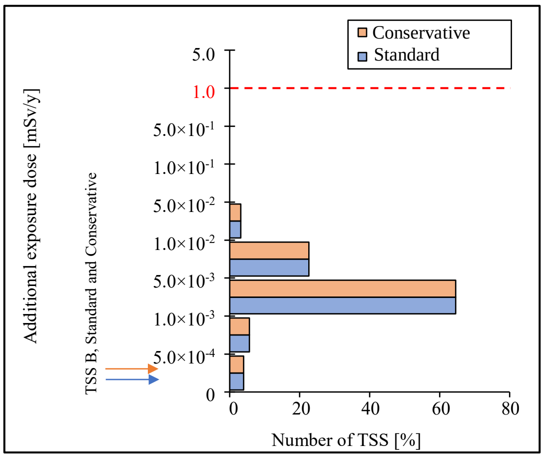


Figure 16. Additional exposure dose using estimated ^{137}Cs (Managed Forest scenario (Adult))

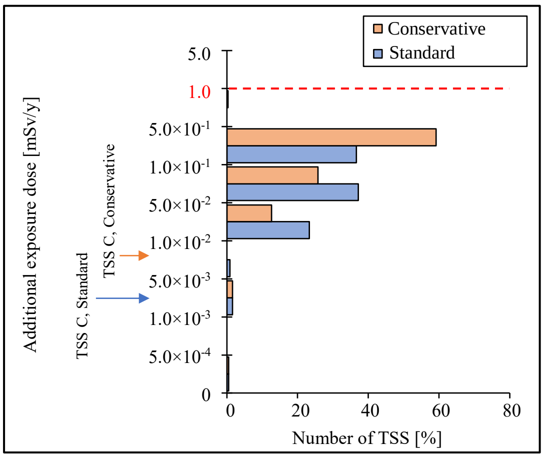


Figure 17. Additional exposure dose using estimated ^{137}Cs (Residence scenario (Adult))

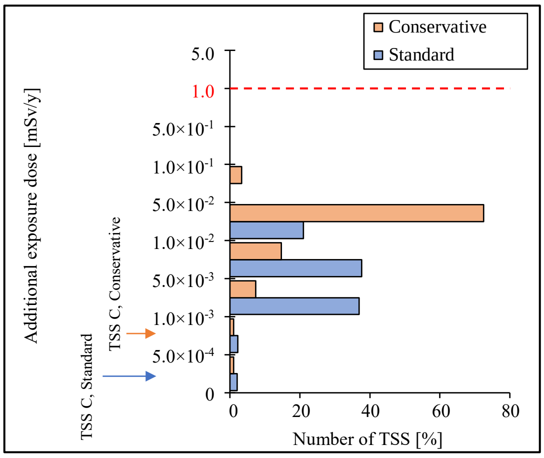


Figure 18. Additional exposure dose using estimated ^{137}Cs (Park scenario (Adult))

7. Conclusions

The additional exposure dose per unit concentration of radioactive cesium in the soil (1 Bq/kg) was calculated for possible land uses at the former TSS. The results of the calculations using the standard data showed that the largest potential doses would be calculated for the Residence scenario and the 1 to 6 years old age group.

As described above, by using a unit concentration of radioactive cesium in soil, which can be scaled using the actual soil contamination level, the method can be used to estimate the additional exposure dose according to the various land uses that could occur in the future.

Case study calculations were performed to calculate the exposure dose for three TSS sites, A, B and C, based on measured data on cesium concentrations in soil. Further calculations were made using measured data on the air dose at TSS first to estimate cesium concentrations in soil and second to calculate the exposure doses at those sites. For all scenarios considered, the expected doses are well below 1 mSv/year. In addition, the dose values obtained using conservative parameter values were also below 1 mSv/year for all studied TSSs. This means that there is very low probability that any individual from the potentially exposed population would receive an annual dose above the long-term goal. It should be noted that the assessment results are very cautious because multiple parameter values are set conservatively.

The above results can be provided to the people and should effectively assist those managing the former TSSs and those who have concerns over the use of the former TSS.

In addition, since the assessment method in this study is general and can be widely used, it can be expected that the present assessment method would be highly applicable to dose assessment for sites other than the sites of former TSSs.

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Parameter (average and standard values) for the dose assessment

Table A1. Parameter for the dose assessment for all scenarios

No.	Parameter		Symbol	Unit	Value	Basis
①	Radionuclide concentration	^{134}Cs	$C_a(i)$	Bq/kgDW	-	The ratio of cesium-134 to cesium-137 present at the time of the Fukushima Daiichi Nuclear Power Plant accident was set to 1:1 and physical attenuation was taken into account in the calculations.
②		^{137}Cs			-	
③	Shielding (screening) factor (outside)		$S_S(i)$	-	1	Atomic Energy Society of Japan, Safety Assessment Method for Near Surface Disposal : 2016, 2018
④	Dose conversion factors for external exposure (^{134}Cs)	Adult	$D_{CF,EXT}(i)$	Sv/h per Bq/kgDW	2.7×10^{-10}	Dose conversion factors for external exposure (mSv/h per kBq/m^2) for a weight buffer depth of 1 g/cm2 of cesium-134 and cesium-137 in soil were reported by Satoh et al. (2016) for different ages. To obtain the dose conversion factors in units of Bq/kg (Sv/h per Bq/kgDW), the density of soil ⑫ and the depth of soil to be sampled (0.05 m) were multiplied by the above factors.
⑤		1-6 years old			3.4×10^{-10}	
⑥		7-14 years old			2.9×10^{-10}	
⑦		15-19 years old			2.7×10^{-10}	
⑧	Dose conversion factors for external exposure (^{137}Cs)	Adult			9.8×10^{-11}	
⑨		1-6 years old			1.3×10^{-10}	
⑩		7-14 years old			1.1×10^{-10}	
⑪		15-19 years old			1.0×10^{-10}	
⑫	Density of soil in former TSS		-	kgDW/m^3	1,600	US NRC「Regulatory Guide 1.109. Revision 1」(1977)
⑬	Dose conversion factors for Internal exposure by ingestion (^{134}Cs)	Adult	$D_{CF,ING}(i)$	Sv/Bq	1.9×10^{-8}	ICRP publ.72(1996) The values for adults, 1, 10, and 15 years old listed in the above document were used, respectively.
⑭		1-6 years old			1.6×10^{-8}	
⑮		7-14 years old			1.4×10^{-8}	
⑯		15-19 years old			1.9×10^{-8}	
⑰	Dose conversion factors for Internal exposure by ingestion (^{137}Cs)	Adult			1.3×10^{-8}	
⑱		1-6 years old			1.2×10^{-8}	
⑲		7-14 years old			1.0×10^{-8}	
⑳		15-19 years old			1.3×10^{-8}	

㉑	Soil intake per hour	Adult	M_s	kgDW/h	4.2×10^{-4}	The daily intake of soil ㉕-㉘ was divided by 24 hours.
㉒		1-6 years old			1.7×10^{-3}	
㉓		7-14 years old			1.3×10^{-3}	
㉔		15-19 years old			4.2×10^{-4}	
㉕	Daily intake of soil	Adult	-	mgDW/day	10	U.S. EPA, Exposure Factors Handbook (2011), 2017, Chapter 5 revised. Values for 12 year olds through adults listed in the above document were used for the adults and 15-19 years old category. Values for 1-2 year olds listed in the above document were used for the 1-6 year old category.Values for ages 6-12 years described in the above document were used for the 7-14 year old category.
㉖		1-6 years old			40	
㉗		7-14 years old			30	
㉘		15-19 years old			10	
㉙	Concentration factor of specific activity in the fine fraction (soil intake)		$f_{c,s}$	-	2	IAEA SRS No.44, 2005
㉚	Dose conversion factors for Internal exposure by inhalation (^{134}Cs)	Adult	$D_{CF,INH}(i)$	Sv/Bq	6.6×10^{-9}	ICRP publ.72(1996) The values for adults, 1, 10, and 15 years old listed in the above document were used, respectively.
㉛		1-6 years old			7.3×10^{-9}	
㉜		7-14 years old			5.3×10^{-9}	
㉝		15-19 years old			6.3×10^{-9}	
㉞	Dose conversion factors for Internal exposure by inhalation (^{137}Cs)	Adult			4.6×10^{-9}	
㉟		1-6 years old			5.4×10^{-9}	
㊱		7-14 years old			3.7×10^{-9}	
㊲		15-19 years old			4.4×10^{-9}	
㊳	Breathing rate		B_A	m^3/h	1.2	Safety Assessment Method for Near Surface Disposal: 2016, Atomic Energy Society of Japan , 2018
㊴	Airborne dust concentration		d_R	$kgDW/m^3$	5.0×10^{-7}	IAEA SRS No.44 (2005)
㊵	Concentration factor of specific activity in the fine fraction (inhalation soil)		$f_{c,d}$	-	4	IAEA SRS No.44 (2005)

Table A2. Parameter for the dose assessment for Paddy scenario

No.	Parameter	Symbol	Unit	Value	Basis
①	External exposure time and Soil ingestion time	t_s $t_{s,ing}$	h/year	183	Annual working hours for rice cultivation ③ multiplied by the percentage of working hours at the former of TSS④ .210 h/year×0.75=183 h/year
②	Area of the former TSS	-	m^2	8,511	Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of former TSSs in the prefecture, where the original land use was paddy fields, was set at 8,511 m^2.
③	Annual working hours for rice cultivation	-	h/year	210	From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", we calculated the working hours per person by area category by dividing the working hours by the total number of persons in rice farming. The value for the area category to which the area of the former temporary storage area ② corresponds was used as the average annual working hours.
④	Percentage of annual hours worked in the former TSS	-	-	0.75	The percentage of working hours in paddy fields was obtained from the 'working hours by operation' (i.e the different types of work performed) in rice cultivation from the "Agricultural Management Statistics Survey_Agricultural Production Costs in 2019" by the Ministry of Agriculture, Forestry and Fisheries.

⑤	Annual rice consumption	Adult	M_f	FWkg/year	54	From the National Health and Nutrition Survey (2019) of the Ministry of Health, Labour and Welfare, the average daily intake of rice for each age group was multiplied by 365 to obtain the annual intake of rice. Furthermore, as this value is the weight of the cooked rice, it was assumed to be the weight after cooking, multiplied by 0.5. Rice intake for adults was taken as the average for those aged 20 and over. For age groups other than adults, the average value for the relevant age group was used.
⑥		1-6 years old			35	
⑦		7-14 years old			61	
⑧		15-19 years old			78	
⑨	Transfer factor of radionuclide i from soil to agricultural product		$T_{R,f}(i)$	Bq/kgFW per Bq/kgDW	0.04	IAEA SRS No19, 2001
⑩	Market dilution factor of food		G_f	-	0.5	Safety Assessment Method for Near Surface Disposal: 2016, Atomic Energy Society of Japan, 2018
⑪	Dust inhalation time		$t_{s,inh}$	h/year	53	Annual working hours for rice cultivation ③ were multiplied by the percentage of annual hours worked in the former TSS ④ and the percentage of annual working hours related to rice cultivation that are potentially dusty ⑫. 210 h/year×0.75×0.29=53 h/year
⑫	Percentage of annual working hours related to rice cultivation that are potentially dusty		-	-	0.29	From the statistical data of the MAFF, we obtained the percentage of working hours when the paddy fields were dry from the working hours by operation in rice farming.

Table A3. Parameter for the dose assessment for Cropland (vegetable) scenario

<table>
<tr><th>No.</th><th colspan="2">Parameter</th><th>Symbol</th><th>Unit</th><th>Value</th><th>Basis</th></tr>
<tr><td>①</td><td colspan="2">External exposure time,
Soil ingestion time and
Dust inhalation time</td><td>t_s
$t_{s,ing}$
$t_{s,inh}$</td><td>h/year</td><td>858</td><td>Annual working hours for vegetable cultivation③ multiplied by the percentage of working hours at the former of TSS④.
1,112 h/year×0.73=858 h/year</td></tr>
<tr><td>②</td><td colspan="2">Area of the former TSS</td><td>-</td><td>m^2</td><td>5,333</td><td>Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of former TSSs in the prefecture, where the original land use was cropland, was set at 5,333 m^2.</td></tr>
<tr><td>③</td><td colspan="2">Annual working time for agricultural production</td><td>-</td><td>h/year</td><td>1,112</td><td>From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", we calculated the working hours per person by area category by dividing the working hours by the total number of persons in vegetable farming. The value for the area category to which the area of the former of TSS ② corresponds was used as the average annual working hours.</td></tr>
<tr><td>④</td><td colspan="2">Percentage of annual hours worked in the former TSS</td><td>-</td><td>-</td><td>0.77</td><td>From the statistical data of MAFF, the percentage of working hours in the field was obtained from the working hours of cucumbers by operation. (Among the vegetables produced in Fukushima Prefecture, cucumbers have the largest area under cultivation.)</td></tr>
<tr><td>⑤</td><td rowspan="4">Annual vegetable consumption</td><td>Adult</td><td rowspan="4">M_f</td><td rowspan="4">kgFW/year</td><td>102</td><td rowspan="4">From the National Health and Nutrition Survey in 2019 of the Ministry of Health, Labour and Welfare, the average daily intake of vegetable for each age group was multiplied by 365 to obtain the annual intake of vegetable. The weight of cooked vegetables was used conservatively, without taking into account the water content, as there are many different methods of cooking. Vegetable intake for adults was taken as the average for those aged 20 and over. For age groups other than adults, the average value for the relevant age group was used.</td></tr>
<tr><td>⑥</td><td>1-6 years old</td><td>47</td></tr>
<tr><td>⑦</td><td>7-14 years old</td><td>88</td></tr>
<tr><td>⑧</td><td>15-19 years old</td><td>89</td></tr>
</table>

⑨	Transfer factor of radionuclide i from soil to agricultural product	$T_{R,f}(i)$	Bq/kgFW per Bq/kgDW	0.04	IAEA SRS No19, 2001
⑩	Market dilution factor of food	G_f	-	0.5	Safety Assessment Method for Near Surface Disposal: 2016, Atomic Energy Society of Japan , 2018

Table A4. Parameter for the dose assessment for Cropland (flower) scenario

No.	Parameter	Symbol	Unit	Value	Basis
①	External exposure time, Soil ingestion time and Dust inhalation time	t_s $t_{s,ing}$ $t_{s,inh}$	h/year	852	Annual working hours for flower cultivation ③ multiplied by the percentage of working hours at the former of TSS④. 1,119 h/year×0.76=852 h/year
②	Area of the former TSS	-	m^2	5,333	Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of former TSSs in the prefecture, where the original land use was cropland, was set at 5,333 m^2.
③	Annual working time for agricultural production	-	h/year	1,119	From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", we calculated the working hours per person by area category by dividing the working hours by the total number of persons in flower farming. The value for the area category to which the area of the former of TSS ② corresponds was used as the average annual working hours.
④	Percentage of annual hours worked in the former TSS	-	-	0.76	The percentage of working hours in the field was obtained from the working hours for chrysanthemum cultivation by type of work from the Ministry of Agriculture, Forestry and Fisheries' "Agricultural Management Statistics Survey_2007 Management Statistics by Item". The area of cut branches is the largest of the flowers produced in Fukushima Prefecture, but as labour hours by operation are not clear, the area of chrysanthemums, the second largest crop, was selected.

Table A5. Parameter for the dose assessment for Orchard scenario

<table>
<tr><th>No.</th><th colspan="2">Parameter</th><th>Symbol</th><th>Unit</th><th>Value</th><th>Basis</th></tr>
<tr><td>①</td><td colspan="2">External exposure time,
Soil ingestion time and
Dust inhalation time</td><td>t_s
$t_{s,ing}$
$t_{s,inh}$</td><td>h/year</td><td>540</td><td>Annual working hours for fruit cultivation ③ multiplied by the percentage of working hours at the former of TSS④
597 h/year×0.90=540 h/year</td></tr>
<tr><td>②</td><td colspan="2">Area of the former TSS</td><td>-</td><td>m^2</td><td>5,333</td><td>Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of former TSSs in the prefecture, where the original land use was cropland, was set at 5,333 m^2.</td></tr>
<tr><td>③</td><td colspan="2">Annual working time for agricultural production</td><td>-</td><td>h/year</td><td>597</td><td>From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", we calculated the working hours per person by area category by dividing the working hours by the total number of persons in fruit farming. The value for the area category to which the area of the former of TSS (2) corresponds was used as the average annual working hours.</td></tr>
<tr><td>④</td><td colspan="2">Percentage of annual hours worked in the former TSS</td><td>-</td><td>-</td><td>0.90</td><td>From the statistical data of MAFF, the percentage of working hours in the vineyard was obtained from the working hours of peaches by operation.
*Among the fruits produced in Fukushima Prefecture, peaches have the largest cropping area.</td></tr>
<tr><td>⑤</td><td rowspan="4">Annual intake of fruits</td><td>Adult</td><td rowspan="4">M_f</td><td rowspan="4">kgFW/year</td><td>37</td><td rowspan="4">From the National Health and Nutrition Survey in 2019 of the Ministry of Health, Labour and Welfare, the average daily intake of fruit for each age group was multiplied by 365 to obtain the annual intake of fruit.</td></tr>
<tr><td>⑥</td><td>1-6 years old</td><td>34</td></tr>
<tr><td>⑦</td><td>7-14 years old</td><td>27</td></tr>
<tr><td>⑧</td><td>15-19 years old</td><td>24</td></tr>
<tr><td>⑨</td><td colspan="2">Transfer factor of radionuclide i from soil to fruit</td><td>$T_{R,f}(i)$</td><td>Bq/kgFW per Bq/kgDW</td><td>0.04</td><td>IAEA SRS No19, 2001</td></tr>
</table>

⑩	Market dilution factor of food	G_f	-	0.5	Atomic Energy Society of Japan, Safety Assessment Method for Near Surface Disposal : 2016, 2018

Table A6. Parameter for the dose assessment for Pasture (milk cow) scenario

No.	Parameter		Symbol	Unit	Value	Basis
①	External exposure time, Soil ingestion time and Dust inhalation time		t_s $t_{s,ing}$ $t_{s,inh}$	h/year	1,244	From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", the working hours per person were calculated by dividing the working hours by the total number of people in each category for raising milk cows. The exposure time is defined as the value of the number of milk cows in the number of cows category to which the number of milk cows (2) corresponds.
②	Number of milk cows raised		-	head	41.7	From the statistical data of MAFF, we selected the average number of milk cows per household raised in Fukushima Prefecture.
③	Annual intake of milk products	Adult	M_f	kgFW/year	23	From the National Health and Nutrition Survey in 2019 of the Ministry of Health, Labour and Welfare, the average daily intake of milk for each age group was multiplied by 365 to obtain the annual intake of milk.
④		1-6 years old			52	
⑤		7-14 years old			92	
⑥		15-19 years old			36	
⑦	Transfer factor of radionuclide i from soil to grass		$T_{R,p}(i)$	Bq/kgDW per Bq/kgDW	1	IAEA SRS No19, 2001 In Fukushima Prefecture, measures to suppress absorption of radioactive cesium by fertilization with exchangeable potassium are encouraged by Fukushima Prefecture's "Guidelines for Decontamination and Technical Measures Concerning Measures against Radioactive Cesium in Agricultural Crops," but the transfer coefficient on the left does not take these measures into account.
⑧	Livestock feed intake		M_g	kgDW/day	16	IAEA TRS No364, 1994
⑨	Market dilution factor of feed (grass)		f_r	-	0.12	Annual pasture production⑪ was divided by Annual requirement of feed (pasture)⑩.

⑩	Annual requirement of feed (pasture)	-	kgDW/year	243,528	The feed intake per cow⑧ and the number of dairy cows② were calculated as follows. 16 kgDW/day × 42 × 365 day = 243,528 kgDW/year
⑪	Annual pasture production	-	kgDW/year	29,741	The area available for pasture seeding⑫ and the annual pasture yields⑮ and the Moisture percentage of pasture ⑯ were used as follows. 54,142 m^2×3.37 kgFW/m^2 ×(1-0.837) = 29,741 kgDW/year
⑫	Area available for pasture seeding	-	m^2	54,142	Difference between the area of the former TSS ⑬ and the area of the cattle barn ⑭.
⑬	Area of the former TSS	-	m^2	54,371	Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of former TSSs in the prefecture, where the original land use was pasture, was set at 54,371 m^2.
⑭	Area of barn	-	m^2	229	According to the "Grassland Development and Improvement Project Plan Design Standards" (2021) by the Japan Grassland and Livestock Seed Association, the area required per dairy cow between 16 and 24 months of age is 5.5 m^2. This was multiplied by 41.7 cows, which is the number of dairy cows per household ② in dairy farms in Fukushima Prefecture.
⑮	Annual pasture yields	-	kgFW/m^2	3.37	Calculated based on the national average of yields per 1,000 m^2 of grass in the "Crop Survey 2020 (Regular Crops, Forage Crops, and Handicraft Crops)" (2020) of the Ministry of Agriculture, Forestry and Fisheries of Japan.
⑯	Moisture percentage of pasture	-	-	0.837	The average value of 83.7 % was used for Italian ryegrass, since the moisture percentage of stems and leaves is considered to be 84.6 % and 82.8 %, respectively, according to Yamashita, et al. (1968).
⑰	Transfer factor from feed to livestock products	$T_{AM}(i)$	day/kgFW	0.01	IAEA SRS No19, 2001
⑱	Market dilution factor of food	G_f	-	0.5	Atomic Energy Society of Japan, Safety Assessment Method for Near Surface Disposal: 2016, 2018

Table A7. Parameter for the dose assessment for Pasture (beef cattle) scenario

No.	Parameter	Symbol	Unit	Value	Basis
①	External exposure time, Soil ingestion time and Dust inhalation time	t_s $t_{s,ing}$ $t_{s,inh}$	h/year	928	From the Ministry of Agriculture, Forestry and Fisheries' "Statistical Survey of Agricultural Management _ Management Statistics by Type of Farming in 2019", the working hours per person were calculated by dividing the working hours by the total number of people in each category for raising beef cattle. The exposure time is defined as the value of the number of beef cattle in the number of cattle category to which the number of beef cattle ② corresponds.
②	Number of beef cattle raised	-	head	28.9	From the statistical data of MAFF, we selected the average number of beef cattle per household raised in Fukushima Prefecture.

Table A8. Parameter for the dose assessment for Managed Forest scenario

No.	Parameter	Symbol	Unit	Value	Basis
①	External exposure time, Soil ingestion time and Dust inhalation time	t_s $t_{s,ing}$ $t_{s,inh}$	h/year	313	Labor hours per person per area size were obtained from the Ministry of Agriculture, Forestry and Fisheries' "Survey of Forestry Management Statistics_Report on Forestry Management Statistics in 2018," based on the number of workers per management unit by area size and labor hours for forestry, material production (logging, etc.), and other operations. The average area of the temporary storage sites where the original land use was forest was 118 a. However, since there is no area classification that matches this, the values between 2,000 and 5,000 a in the above statistical data were used. (Even taking into account the physical attenuation of radioactive cesium, the most conservative result is the assessment assuming logging.)
②	Area of the former TSS	-	m^2	11,775	Based on the results of a survey conducted by the Decontamination Division of Fukushima Prefecture, the average area of temporary storage sites in the prefecture was set at 11,775 m^2.

Table A9. Parameter for the dose assessment for Residence scenario

No.	Parameter		Symbol	Unit	Value	Basis
①	External exposure time (indoor)	Adult	t_s	h/year	5,778	The annual time spent at home ⑤ to ⑧ minus the annual activity time related to the kitchen garden ⑩ to ⑬ was used as the indoor external exposure time.
②		1-6 years old			6,998	
③		7-14 years old			5,315	
④		15-19 years old			5,315	
⑤	Annual home time	Adult	-	h/year	5,920	From the NHK Broadcasting Culture Research Institute's National Survey on Living Time (2020), we calculated the annual amount of time spent at home by age, gender, and occupation by multiplying the average time spent at home per day on weekdays, Saturdays, and Sundays by the number of weekdays, Saturdays, and Sundays (national holidays are counted as Sundays) in FY2020. In the adult age group, the value for females in their 40s, which has the largest value among the categories of males and females in their 40s and above, was used. (This is because it is known that the average age of people in Fukushima Prefecture is 49.4 years old according to the National Institute of Population and Social Security Research "Demographic Data Book (2021 edition)"). For the age groups 7-14 and 15-19, the values for teenage males were used because they were larger when compared to the values for teenage males and females. To account for variation among years, rounding up to the nearest 1 was performed.
⑥		1-6 years old			7,140	
⑦		7-14 years old			5,400	
⑧		15-19 years old			5,400	
⑨	Shielding (screening) factor (inside)		$S_S(i)$	-	0.4	This is based on the Nuclear Safety Commission's "Disaster Prevention Measures for Nuclear Facilities" (June 1980).

⑩	External exposure time, Soil ingestion time and Dust inhalation time (Outdoor, kitchen garden)	Adult	t_s $t_{s,ing}$ $t_{s,inh}$	h/year	142	From Takatori et al. "FY 2008 National Land Policy Related Research Support Project: Report on Research Results Calculation and Visualization of Workload for Landscape Management for Appropriate Management of National Land - Targeting Eight Central Japan Prefectures", it is the average annual work hours for home gardens by age group. For adults, we used values for people in their 40s (because the average age in Fukushima Prefecture is known to be 49.4 years according to the National Institute of Population and Social Security Research's Demographic Data Book (2021 edition)). The average age is 49.4 years old. For the age group 1-6 years old, as there is no corresponding age group, it is assumed that the children are accompanied by an adult and the value is taken as 40s.
⑪		1-6 years old			142	
⑫		7-14 years old			85	
⑬		15-19 years old			85	
⑭	Annual vegetable consumption	Adult	M_f	kgFW/year	102	From the National Health and Nutrition Survey in 2019 of the Ministry of Health, Labour and Welfare, the average daily intake of vegetable for each age group was multiplied by 365 to obtain the annual intake of vegetable. Vegetable intake for adults was taken as the average for those aged 20 and over. For age groups other than adults, the average value for the relevant age group was used.
⑮		1-6 years old			47	
⑯		7-14 years old			88	
⑰		15-19 years old			89	
⑱	Transfer factor of radionuclide i from soil to agricultural product		$T_{R,f}(i)$	Bq/kg FW per Bq/kg DW	0.04	IAEA SRS No19, 2001
⑲	Market dilution factor of food		G_f	-	0.1	Atomic Energy Society of Japan, Safety Assessment Method for Shallow Underground Trench Disposal: 2013 (2014).

Table A10. Parameter for the dose assessment for Park scenario

No.	Parameter		Symbol	Unit	Value	Basis
①	External exposure time, Soil ingestion time and Dust inhalation time	Adult	t_s $t_{s,ing}$ $t_{s,inh}$	h/year	180	From the Ministry of Land, Infrastructure, Transport and Tourism's 2014 Survey of Urban Park Use (2015), the average daily time spent in city parks by age group on weekdays and holidays was multiplied by the number of days visited to obtain the annual time spent in parks. The number of days of visit was calculated on the assumption that the average frequency of visit was 2-3 times a week, so the respondents visited the park twice a week on weekends and once a weekday. For the adult category, the exposure time was set using the value for adults (19-64 years). For the 1-6 age group, the values are those before school age. For the 7-14 age group, we used the value for the upper primary schools students (grades 4-6), who have the greatest annual time in preschool among the lower primary schools students (grades 1-3), upper primary schools students (grades 4-6), and junior high and high school students and others (ages 12-18). For the 15-19 age group, the values are those of junior high and high school students and others (12-18 years). To account for variation among years, rounding up to the nearest 1 was performed.
②		1-6 years old			240	
③		7-14 years old			220	
④		15-19 years old			210	

Method of setting conservative parameter values

External exposure time(t_s), Soil ingestion time in former TSS ($t_{s,ing}$), Dust inhalation time in former TSS ($t_{s,inh}$)

The following were considered for each scenario. The soil ingestion time ($t_{s,ing}$) and the dust inhalation time in former TSS ($t_{s,inh}$) are linked to the external exposure time (t_s), and these three parameters have the same value except for the Paddy and Residence scenarios.

Paddy

The working hours in the former TSS per person for each area size category were calculated based on the total annual working hours (average), the total number of people (average) and the ratio of working hours by task (average) for each area size category in the statistical data of the Ministry of Agriculture, Forestry and Fisheries [1, 2], and used as the external exposure time and the soil ingestion time in the Paddy scenario. The dust inhalation time was defined as the external exposure time and the soil ingestion time multiplied by the ratio (average value) of the time when the paddy field was dry (time when dust could be generated).

Of the working hours per worker per area size category calculated as above, the values for the 300,000-500,000 m^2 category, that is the longest working hours in the largest TSS area size of 363,000 m^2 or less were used conservatively. The formulas for deriving the parameter values are as follows.

Paddy（$t_s, t_{s,ing}$）: External exposure time and soil ingestion time in the Paddy scenario
Paddy（$t_s, t_{s,ing}$）= total annual working hours ÷ total number of people × Percentage of time spent in paddy fields out of the total time spent on rice cultivation

Paddy（$t_{s,inh}$）: Dust inhalation time in the Paddy scenario
Paddy（$t_{s,inh}$）= total annual working hours ÷ total number of people × Percentage of time spent in paddy fields out of the total time spent on rice cultivation × Percentage of time that paddy fields are dry per year

Cropland (vegetable and flower) and Orchard

The working hours in the former TSS per person for each area category were calculated based on the total annual working hours (average), the total number of people (average), and the ratio of working hours by work (average) for each area category in the statistical data of the Ministry of Agriculture, Forestry and Fisheries [1, 3], and the external exposure time, the soil ingestion time and the dust inhalation time in the Cropland (vegetables and flowers) and Orchard scenarios were used.

Of the working hours per worker per area size category calculated as above, the values for the area size category (the values of 100,000 to 150,000 m^2 for the Cropland (vegetable) scenario, 30,000 m^2 or more for the Cropland (flower) scenario, and 30,000 to 50,000 m^2 for the Orchard scenario), that is the longest working hours in the largest TSS area size of 363,000 m^2 or less were used conservatively. The formula for deriving the parameter values is as follows.

Cropland and Orchard $(t_s, t_{s,ing}, t_{s,inh})$: External exposure time, etc. in Cropland and Orchard scenarios

Cropland and Orchard $(t_s, t_{s,ing}, t_{s,inh})$ = total annual working hours ÷ total number of people × Percentage of time spent in the field growing crops

Pasture (milk cow and beef cattle)

The working hours per person in the former TSS for each head number category were calculated based on the total working hours (average) and the total number of persons (average) for each head number category in the statistical data [1] provided by the Ministry of Agriculture, Forestry and Fisheries, and used as the external exposure time, the soil ingestion time and the dust inhalation time in the Pasture (milk cow and beef cattle) scenario. Since the percentage of working hours in pastures out of total working hours is unknown, it was assumed that the workers were always in pastures during working hours.

Of the labor hours per person for each head number category calculated as above, the values for the head number category (the values of over 200 head for the Pasture (milk cow) scenario and over 500 head for the Pasture (beef cattle) scenario), that is the longest working hours in the highest head (over 200 head or less for the Pasture (milk cow) scenario and over 500 head or less for the Pasture (beef cattle) scenario*) were used conservatively. The formula for deriving the parameter values is as follows.

Pasture $(t_s, t_{s,ing}, t_{s,inh})$: External exposure time, etc. in Pasture (milk cow and beef cattle) scenarios

Pasture $(t_s, t_{s,ing}, t_{s,inh})$ = total annual working hours ÷ total number of people

Managed Forest

The working hours per person in the former TSS for each area size category were calculated, based on the total working hours and the total number of people involved in forest growing, logging, and other works for each area size category in the statistical data provided by the Ministry of Agriculture, Forestry and Fisheries [4], and used as the external exposure time, the soil ingestion time and the dust inhalation time in the Managed Forest scenario. Since the percentage of working hours in forest out of total working hours is unknown, it was assumed that the workers were

* It is known that there are some dairy cattle farms with more than 200 head of dairy cattle and beef cattle farms with more than 500 head of beef cattle in Fukushima Prefecture[5)].

always in forest during working hours.

Of the annual per capita labor hours per area size category calculated as above, the longest per capita labor hours in the area size category below 363,000 m^2 (the maximum TSS area) were used as the conservative exposure hours. However, the smallest area category in the statistical data of the Ministry of Agriculture, Forestry and Fisheries [31] is between 200,000 ~ 500,000 m^2, resulting in the same values for the standard and conservative parameters.

Managed Forest $(t_s, t_{s,ing}, t_{s,inh})$: External exposure time, etc. in Managed Forest scenario
Managed Forest $(t_s, t_{s,ing}, t_{s,inh})$ = total annual working hours ÷ total number of people

Residence

Although there are two exposure areas in the residence, indoor and outdoor, we thought that a conservative value for the indoor area, which accounts for the majority of the exposure time, would be sufficient to consider the uncertainties in the overall Residence scenario.

The annual time spent at home was calculated from the average daily time spent at home on weekdays, Saturdays, Sundays and public holidays for each age, gender, and occupation in the statistical data of the NHK Broadcasting Culture Research Institute [6], less the annual activity time (average) related to home vegetable gardening (survey by Takatori et al.[7]), and the value was used as the indoor external exposure time in the Residence scenario. Since the statistical data of the NHK Broadcasting Culture Research Institute showed the mean and standard deviation of the time spent at home per day, the value obtained by adding the mean value and standard deviation value was used as the conservative exposure time. In the adult age categories, for the values showed by the statistical data for males and females in their twenties and above, the value of females in their seventies with a large value of the sum of the mean and standard deviation values was used as conservative exposure time. The values used for the following groups were also the corresponding values from the same statistical data. For the age groups of 7-14 and 15-19 years old, the values for teenage males and females with the highest value of the sum of the mean and standard deviation values were used as conservative exposure time. For the age group of 1-6 years old, it was assumed that they always spend time with their parents, and the mean value of the housewife's home time plus the standard deviation value was used as a conservative exposure time. However, for adults and the age group 1-6 years old, the sum of the mean and standard deviation values exceeded 8,760 hours, which is the total time spent at home per year, so 8,760 hours was used as a conservative annual time spent at home. The formulas for deriving the parameter values are as follows.

Residence (t_s) : Indoor external exposure time in Residence scenario
Residence (t_s) = Annual time spent at home on weekday, Saturday, Sunday, and public

holiday - Annual activity time in the kitchen garden

Annual time spent at home on weekday = time spent at home per weekday × number of weekdays per year

Annual time spent at home on Saturday = time spent at home per day on Saturday × number of Saturdays per year

Annual time spent at home on Sunday and public holiday = Time spent at home per day on Sundays × Number of Sundays and public holidays per year

*The soil ingestion and the dust inhalation were assumed not to occur indoors for the assessment in the present study.

Park

The annual time spent in the park was calculated from the average time spent in the park on weekdays, Saturdays and Sundays and public holidays for each age group and the frequency of visits to the park in the statistical data of the Ministry of Land, Infrastructure, Transport and Tourism [8], and was used as the external exposure time, the soil ingestion time and the dust inhalation time in the Park scenario.

The Ministry of Land, Infrastructure, Transport and Tourism's statistical data indicates that there is a certain percentage of each age group that visits the park almost every day, so we calculated the annual time spent in the park based on the assumption that they visit the park every day, which are these conservative values. For the adult age group, the time was set using the value for adults (elderly) value showed by the statistical data. The values used for the following groups were also the corresponding values from the same statistical data. For the age group of 1-6 years old, the value before school age was used as a conservative exposure time. For the age group of 7-14 years old, among the lower elementary school students (grades 1-3), upper elementary school students (grades 4-6), and middle school and high school students, etc. (ages 12-18), the value for the upper elementary school students (grades 4-6), who have the largest annual time in school, was used as a conservative exposure time. For the age group of 15-19 years old, the value for junior high school students, high school students, etc. (12-18 years old) and adults (19-64 years old), which has the maximum annual time in school, was used as a conservative exposure time. The formulas for deriving the parameter values are as follows.

Park $(t_s, t_{s,ing}, t_{s,inh})$: External exposure time, etc. in Park scenario

Park $(t_s, t_{s,ing}, t_{s,inh})$ = Annual time spent in preschool on weekdays + Annual time spent in preschool on holidays

Annual time spent in preschool on weekdays = time spent in preschool per day on weekdays x number of weekdays per year
Annual time spent at home on holidays = Time spent at school per day on holidays × Number of Saturdays, Sundays, and holidays per year

Annual amount of food intake（M_f）

The annual intake of food for each age group in the Paddy, Cropland (vegetables), Orchard and Pasture (milk cow) scenarios was calculated from the average daily intake by food type for each age group in the statistical data [9] of the Ministry of Health, Labor and Welfare. The intake of rice for the Paddy scenario, vegetables for the Cropland (vegetable) scenarios, fruits for the Orchard scenario, and milk for the Pasture (milk cow) scenario were chosen. For the rice, the intake was set at one-half [10] the value in the statistical data, considering that it was the weight of rice after cooking. Since the statistical data [9] of the Ministry of Health, Labor and Welfare (MHLW) shows the mean and standard deviation values, the sum of the mean and standard deviation values was used as a conservative food intake. For adults, conservative food intake values were defined using the value for the age group in which the sum of the mean and standard deviation values was the largest (20-29 years for rice and milk cow, 70-79 years for vegetables and fruits). For age groups other than adults, conservative food intake was defined as the sum of the mean and standard deviation values for ages 1-6 years old, 7-14 years old, and 15-19 years old, respectively. The formulas for deriving the parameter values are as follows.

Paddy（M_f）: annual food intake in Paddy scenario
Paddy（M_f）= daily rice Intake × 365 ÷ 2

Other than paddy（M_f）: annual food intake for Cropland (vegetables), Orchard, and Pasture (milk cow) scenarios
Other than paddy（M_f）= daily intake × 365

Market dilution factor of food（G_f）

For the market dilution factor（G_f）in the Paddy, Cropland (vegetables), Orchard, and Pasture (milk cow) scenarios, although the AESJ standard [11] recommends that the market dilution factor of the crop which is considered in the internal exposure model for ingestion from food and drinking water is 0.5, the present study used 1 for the conservative case based on the assumption that all the specific food consumed in a year originated from the TSS sites.

Market dilution factor of feed（f_r）

With respect to the conservative external exposure time in the Pasture (milk cow) scenario, the number of is over 200. When the amount of grass intake per day per cow is 16 kgDW [12], a total dry weight of grass of 1,168,000 kg is required per year for 200 cows. The area where grass can be cultivated in the TSS is the area subtracting the area of the barn. In the cattle barn, since the area required for each dairy cow aged 16-24 months is 5.5 m^2 [13], 1,100 m^2 are required for 200 dairy cows. Therefore, the maximum area of the site of the TSS is 363,000 m^2, so that the area in which grass can be sown is 361,900 m^2.

The average annual yield per unit area of grass is 3.54 kg FW/m^2 at the maximum according to the FY2014-FY2019 statistical data [14, 15, 16, 17, 18, 19, 20] of the Ministry of Agriculture, Forestry and Fisheries. In the case of Italian ryegrass, it is revealed by Yamashita, et al. [21] that the water content of the stem and leaf sheath is 84.6 % and the leaf blade is 82.8 %. Therefore, by considering that 83.7 %, which is the average value of these two values, is the water content of the grass, the annual average yield per unit area of the grass was calculated as 0.58 kg DW/m^2.

When the average annual yield of grass is 0.58 kgDW/m^2, the total annual yield for a pasture area of 361,900 m^2 will be 208,824 kgDW. This is 18% of 1,168,000 kg which is the annual required amount of grass to feed 200 cows, so the conservative value for the market dilution factor for grass was set at 0.18.

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Conversion method from air dose rate in the former TSS to cesium-137 concentration in topsoil

To estimate the cesium-137-derived air dose rate in the former TSS, the cesium-137 derived air dose rate was calculated from the air dose rate in the former TSS and the ratio of cesium-137 to cesium-134 at the time t since the accident, as shown in Equation (C1). The cesium-137 concentration was then calculated by dividing the cesium-137 derived air dose rate by the conversion factor from the cesium-137 concentration in soil to the air dose rate, as in Equation (C2). In the present study, it was assumed that the relaxation mass depth β becomes 1 g/cm^2 for the distribution of cesium on the site of the TSS. From the report of Satoh et al. [1], the conversion factor of cesium-137 in soil to the air dose rate for β = 1 was set to 2.11×10^{-6} mSv/h per kBq/m^2. The coefficient was multiplied by the soil density of 1.6 gDW/cm^3 [2] and soil depth of 5.0 cm to obtain the conversion factor of 1.7×10^{-10} (Sv/h)/(Bq/kgDW).

$$D_{137}(t) = (D(t) - D_{BG}) \frac{\left(\frac{1}{2}\right)^{\frac{t}{T_{137}}}}{k\left(\frac{1}{2}\right)^{\frac{t}{T_{134}}} + \left(\frac{1}{2}\right)^{\frac{t}{T_{137}}}} = (D(t) - D_{BG}) \frac{1}{k\frac{(\frac{1}{2})^{\frac{t}{T_{134}}}}{(\frac{1}{2})^{\frac{t}{T_{137}}}} + 1} \qquad \text{(C1)}$$

$$C_{s_{137}}(t) = \frac{D_{137}(t)}{D_{CF,ADR}} \qquad \text{(C2)}$$

In Eq. (C1), when *D(t)* is less than D_{BG}, Cs_{137}=0. The parameters shown in Eqs. (C1) and (C2) are as follows.

$D_{137}(t)$: Air dose rate calculated based on Cesium-137 at the position of 1 m height from the ground level when time is t [Sv/h]

$C_{s_{137}}(t)$: Concentration of Cesium-137 in soil ［Bq/kgDW］

$D(t)$: Air dose rate at time t obtained by questionnaire survey [Sv/h]

D_{BG} : Air dose rate based on the natural nuclides (The value of municipalities reported by Ando et al.[3]) [Sv/h]

k : Ratio of air dose rates of Cesium-134 to Cesium-137 at the same concentration, which is 2.7 ［-］

t : Elapsed time from accident occurrence (March 15, 2011) ［y］

T_{134} : Half life of Cesium-134, which is 2.0648 y [4]

T_{137} : Half life of Cesium-137, which is 30.1671 y [4]

$D_{CF,ADR}$: Conversion factor to air dose rate from Cesium-137 concentration in soil, which is 1.7×10^{-10} (Sv/h)/(Bq/kgDW)

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