S1 Methods

Estimation of additional effective doses

The additional effective dose from external exposure was estimated as follows [1]:

\[ D_{ee} = \int_{st}^{et} (ADR \times k - BGR) dt \times (t_{out} + t_{in} \times RF) / 24 \]  \hspace{1cm} [eq. S1]

where \( D_{ee} \) is the additional effective dose from external exposure [Sv], \( st \) is the start of the date in the scenario, \( et \) is the end of the date in the scenario, \( ADR \) is the kerma rate in free air [Gy/h], \( k \) is the conversion coefficient from the kerma rate in free air to the effective dose [Sv/Gy], \( BGR \) is the background rate [0.03 \( \mu \)Sv/h] [1], \( t_{out} \) is the time spent outside buildings per day[h], \( t_{in} \) is the time spent inside buildings per day, and \( RF \) is the reduction factor.

\( ADR \) followed the monitoring data, as determined by a fixed radiation monitoring post in the Minamisoma Joint Government building in Minamisoma [2] (Figure S5). This included all radiation exposure to radioiodine and radiocesium from cloud shine and ground shine; the radiation peaked at 21:00 on 12 March and then decreased with time. We used a \( k \) value of 0.75 to estimate the doses in Scenarios 1 and 2 [3,4]. \( RF \) was set at 0.9 for cloud shine before 14 March, whereas \( RF \) was set at 0.4 for ground shine for the period from 14 March onward [1]. The \( RF \) value of 0.4 for ground shine was comparable to the average value of 0.34 observed in households in Fukushima Prefecture [5]. For nursing home staff, \( t_{out} \) and \( t_{in} \) were set at 8 h and 16 h,
respectively [4], whereas for nursing home residents, $t_{\text{out}}$ and $t_{\text{in}}$ were set at 0 h and 24 h. The external exposure dose at the evacuation site was regarded as negligible, thus also resulting in overestimation of the radiation risks avoided after evacuation.

Because the radioactive plume passed before the start date of the scenarios (22 March), doses from inhalation were not included in the estimation of LLEs in either of the evacuation scenarios. To compare the dose levels before 22 March with those in the subsequent 90 d, the doses were approximated as follows [4]:

$$D_{ih} = A_{\text{Cs}} \times I_i \times \sum_{m}(A_m/A_{\text{Cs}})/V_{bm} \times d_{mi} \quad \text{[eq. S2]}$$

Where $D_{ih}$ is the additional effective dose from inhalation [Sv], $m$ is the radionuclide, $A_m$ is the surface activity density of radionuclide $m$ on the ground [Bq m$^{-2}$], $I_i$ is the breathing rate [m$^3$s$^{-1}$], $V_{bm}$ is the bulk deposition velocity of radionuclide $m$ [m s$^{-1}$], and $d_{mi}$ is the effective dose inhalation coefficient for radionuclide $m$ [Sv Bq$^{-1}$]. The median of measured values (99800 Bq m$^{-2}$ [6]) in the city of Minamisoma was used for $A_{\text{Cs}}$. Radionuclides $^{131}\text{I}$, $^{132}\text{I}$, $^{132}\text{Te}$, $^{134}\text{Cs}$, and $^{137}\text{Cs}$ were considered in the assessment.

Doses from ingestion in Minamisoma were assumed to be similar to those in the city of Fukushima, whereas ingestion doses at the evacuation site (in Kanagawa Prefecture, the prefecture neighboring Tokyo) were assumed to similar to those in
Tokyo. The doses followed arithmetic means for males and females ≥19 y old [7]. In this regard, however, for doses due to ingestion of drinking water at the evacuation site, we used monitoring data from the Water Purification Plant in Kanagawa Prefecture [8].

**Cancer risk models**

Lifetime attributable risk (LAR) was calculated from cancer-free survival rates \(S(a, g)\) and a model combining an excess absolute risk (EAR) model and an excess relative risk (ERR) model.

\[
\text{LAR} (D, e, g) = \int_{e+L}^{89} \left[ w \cdot \text{EAR}(D, e, a, g) + (1 - w) \times \text{ERR}(D, e, a, g) \times m(a, g) \right] \frac{S(a, g)}{S(e, g)} da
\]

[eq.S3]

where \(D\) is the organ dose (Sv), \(e\) is age at exposure, \(g\) is sex, \(L\) is the minimum latency period (2 y for leukemia and 5 y for all solid cancers), \(w\) is the weight of the EAR and ERR models combined (0.5), \(a\) is the age attained, and \(m(a, g)\) is the baseline cancer incidence in the unexposed population. For Scenario 1 and 2, the organ (colon and bone marrow) doses were calculated from the additional effective doses and the organ dose to effective dose ratios [9]. For the exposure scenarios, 20-mSv or 100-mSv organ doses were used in the assessment.
Incidence risk models for all solid cancers were as follows:

$$\text{EAR} (D, e, a, g) \text{ or ERR} (D, e, a, g) = (1 + t \times s) \times k_d \times D \times \exp \left[ -g_e \times (e-30) + g_a \times \ln(a/70) \right]$$ \quad [\text{eq.S4}]

where, \( s = -1 \) for males and 1 for females and, for the EAR model, \( t = 0.1622, k_d = 51.63 \times 10^{-4}, g_e = 0.02805, \) and \( g_a = 2.406; \) for the ERR model, \( t = 0.2465, k_d = 0.4666, g_e = 0.01849, \) and \( g_a = -1.621. \)

The incidence risk models and their parameters for leukemia were as follows:

$$\text{EAR} (D, e, a, g) = (\alpha \times D + \beta \times D^2) \times \exp[\kappa_1 \times l_s=\text{female} + \kappa_2 \times \ln (a - e)]$$ \quad [\text{eq.S5}]

where \( \alpha = 7.5165 \times 10^{-4}, \beta/\alpha = 1.03455, \kappa_1 = -0.52526, \kappa_2 = -0.6141, \) and \( l_s=\text{female} = 0 \) for males, 1 for females.

$$\text{ERR} (D, e, a, g) = (\alpha \times D + \beta \times D^2) \times \exp[\kappa_1 \times \ln (a)]$$ \quad [\text{eq.S6}]

where \( \alpha = 864.552, \beta/\alpha = 1.18092, \kappa_1 = -1.647. \)

The mortality risk model for all solid cancers was as follows:

$$\text{ERR} (D, e, a, g) = (\alpha \times D + \beta \times D^2) \times (1 + t \times s) \times \exp[g_e \times (e-30) + g_a \times \ln(a/70)]$$ \quad [\text{eq.S7}]


where $\alpha = 0.22$, $\beta = 0.18$, $t = 0.29$, $g_e = -0.034$, and $g_a = -0.89$.

The mortality risk model for leukemia was as follows:

$$\text{ERR}(D, a) = (\alpha \times D + \beta \times D^2) \times \exp[\gamma \times \ln[a/50]] \quad [\text{eq.S8}]$$

where $\alpha = 1.612$, $\beta = 1.551$, and $\gamma = -1.634$.

**References**


