DOSIMETRY

Outline

- Exposure pathways
- Dose conversions
- Types of calculated doses
- Example exposure pathways
  - Groundshine
  - Resuspension inhalation
  - Cloudshine
  - Direct inhalation
  - Skin deposition
  - Food ingestion
  - Water ingestion
  - Decontamination worker dose

DOSIMETRY

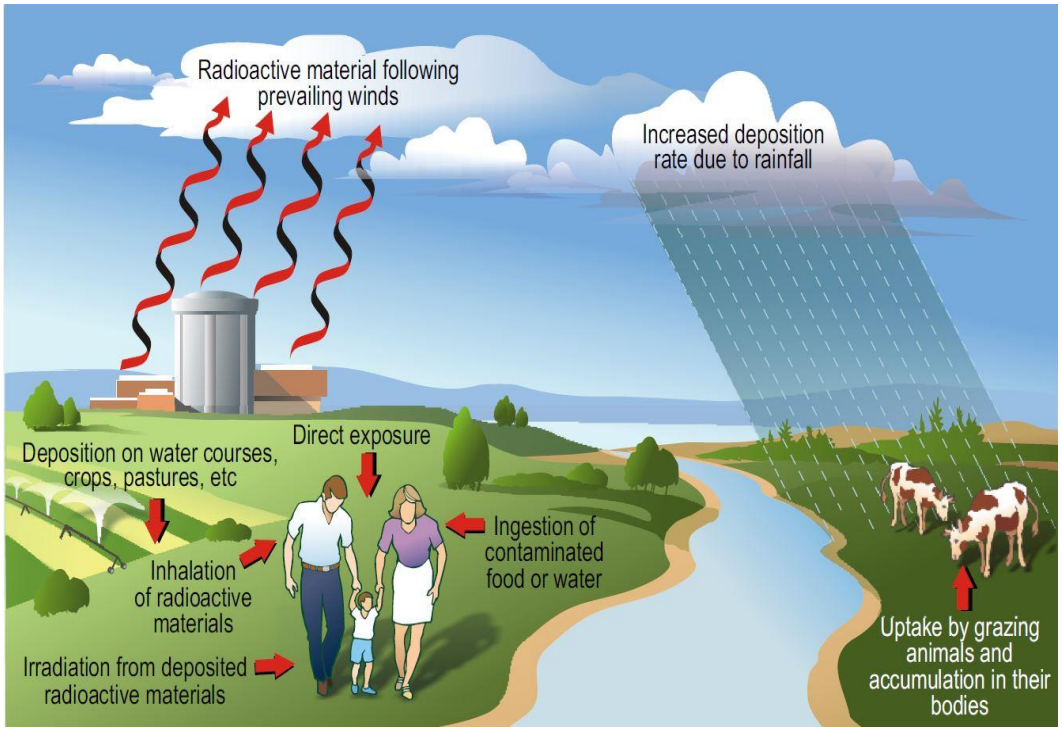
Exposure Pathways

Early Doses

- Cloudshine
- Groundshine
- Direct inhalation
- Resuspension inhalation
- Skin deposition

Late Doses

- Groundshine
- Resuspension inhalation
- Food ingestion
- Water ingestion



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Dose Coefficients

- The dose models use dose coefficients to convert from time-integrated air concentrations or ground concentrations to dose.
- Dose coefficients:
  - read from a user-supplied DCF file
  - depend on the exposure pathway, organ, and radionuclide
  - treat the effective dose as a pseudo-organ
- External pathways use a dose rate coefficient (e.g., *Sv/s per Bq/m^2*)
- Internal pathways (inhalation and ingestion) use an intake-to-dose coefficient (*Sv/Bq*)
- Separate internal dose coefficients are provided for acute, lifetime, and annual doses

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Types of Calculated Doses

- Acute dose
  - The portion of the dose that contributes to early health effects (i.e., accounts for the sparing effect)
  - Includes only early-phase contributions to dose
  - Uses a weighting factor (<1.0) to account for reduced risk associated with protracted internal doses from inhalation
- Lifetime dose
  - The dose that contributes to stochastic health effects (e.g., cancer)
  - Includes both early-phase and late-phase contributions to dose
- Annual dose
  - The same as the lifetime dose, except annual doses are discretized into annual periods
  - Includes both early-phase and late-phase contributions to dose

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Groundshine (EARLY and CHRONC)

The groundshine dose DG_k (*Sv*) to organ *k* in a spatial element for the intermediate or long-term phase is calculated using the following equation:

$$DG_k = \left(\sum_i DRCG_{ik} \cdot GC_i \cdot IEF_i \right) \cdot Y \cdot SFG$$

where

- $DRCG_{ik}$ is the groundshine dose rate coefficient (*Sv–m²/Bq–s*) to the organ *k* for the radionuclide *i*, supplied in the DCF file,
- GC_i is the ground concentration (*Bq/m²*) of radionuclide *i* under the plume centerline, computed separately for the EARLY and CHRONC phases to account for decay and ingrowth,
- IEF_i is the groundshine integrated exposure factor (*s*) for radionuclide *i* for the time period of interest, computed separately for the EARLY and CHRONC phases
- Y is the off-centerline correction factor (dimensionless) of the fine spatial element (EARLY) or the coarse spatial element (CHRONC),
- SFG is the groundshine protection factor (dimensionless) for the time period of interest

DOSIMETRY

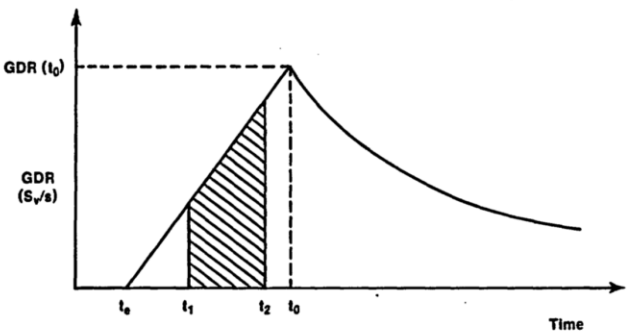
Groundshine (EARLY)

The groundshine integrated exposure factor IEF_i (s) for early phase exposures is given by:

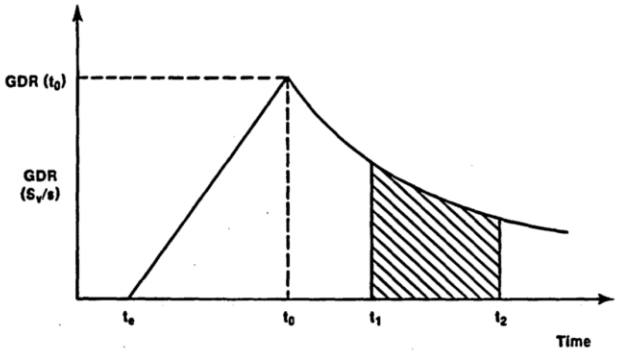
$$IEF_i = \int_{t_1}^{t_2} \frac{(t - t_e)}{(t_0 - t_e)} dt + \int_{t_3}^{t_4} e^{-\lambda_i t} dt$$

where

- t_e and t_0 give the times that the reference location of a plume segment enters and leaves a spatial element
- t_1 and t_2 give the start and end of exposure during plume passage
- t_3 and t_4 give the start and end of exposure after plume passage
- λ_i is the radioactive decay constant of radionuclide *i.*



(a) Exposure During the Plume Passage



(b) Exposure After the Plume Passage

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Groundshine (CHRONC)

The groundshine integrated exposure factor IEF_i (*s)* for intermediate and long-term phase exposures is given by:

$$IEF_i = \frac{1}{DRF_\ell} \int_{t_1}^{t_2} e^{-\lambda_i t} \cdot \left(WC_1 \cdot e^{-\lambda_1 t} + WC_2 \cdot e^{-\lambda_2 t} \right) dt$$

where

- DRF_ℓ is the dose reduction factor (dimensionless) for decontamination level ℓ, if applicable, as specified by the parameter DSRFCT$_\ell$.
- t_1 and t_2 provide the start and end of the exposure period,
- λ_i is the radioactive decay constant (s^{-1}) of radionuclide *i*,
- WC_1 and WC_2 are the groundshine weathering compartment fractions (dimensionless), as specified by GWCOEF, and
- λ_1 and λ_2 are the weathering decay constants (s^{-1}) determined by TGWHLF.

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Resuspension Inhalation (EARLY and CHRONC)

Inhalation dose from resuspended radionuclides DR_k is calculated as follows

$$DR_k = \left(\sum_i DCI_{ik} \cdot GC_i \right) \cdot RF \cdot BR \cdot Y \cdot SFI$$

where

- DCI_{ik} is the inhalation dose coefficient (*Sv/Bq-inhaled*),
- GC_i is the ground concentration (*Bq/m*^{2}) of radionuclide *i* in the spatial element, computed separately for the EARLY and CHRONC phases,
- *RF* is the time-integrated resuspension factor (*s/m*), calculated separately for the EARLY and CHRONC phases
- *BR* is the breathing rate (*m*^{3}*/s*),
- Y is the off-centerline correction factor (dimensionless) of the fine spatial element (EARLY) or the coarse spatial element (CHRONC),
- *SFI* is the inhalation protection factor (dimensionless),

DOSIMETRY

Resuspension Inhalation (EARLY and CHRONC)

The time-integrated resuspension factor *RF* (*s*/*m*) is given by either:

$$RF_{EARLY} = RC \cdot \int_{t_1}^{t_2} e^{-\lambda_r t} \cdot e^{-\lambda_i t}\, dt$$

$$RF_{CHRONC} = \frac{1}{DRF_{\ell}} \int_{t_1}^{t_2} \left(\sum_{m=1}^{3} \left(RC_m \cdot e^{-\lambda_m t} \right) \right) \cdot e^{-\lambda_i t} \cdot dt$$

where

- RC is the early phase resuspension coefficient (m^{-1}),
- λ_r is the early phase resuspension weathering constant (s^{-1})
- λ_i is the decay constant (s^{-1}) of radionuclide *i*,
- t_1 and t_2 provide the start and end of the exposure period,
- DRF_{ℓ} is the dose reduction factor (dimensionless) for decontamination level ℓ if applicable, as specified by the parameter DSRFCT$_{\ell}$
- RC_m is the long-term resuspension coefficient (m^{-1}) for the m^{th} term, and
- λ_m is the long-term resuspension weathering decay constant (s^{-1}) for the m^{th} term

PROTECTIVE ACTIONS

Outline

- Introduction
- Early phase
  - Evacuation and sheltering model
    - Evacuation and sheltering timeline
    - Evacuation transit and routing
    - Evacuation region (circular vs keyhole model)
  - Early Relocation
  - Potassium iodide ingestion
- Intermediate phase
  - Intermediate-phase relocation
- Long-term phase
  - Decontamination
  - Long-term actions for non-farm areas
  - Long-term actions for farm areas

PROTECTIVE ACTIONS

Introduction

- Protective actions reduce radiation exposures.
- Protective actions are a tradeoff: They reduce radiogenic health effects but at a cost of other types of societal and economic impacts.
- MACCS treats the three accident phases as being independent of each other.
- Early phase protective actions (i.e., “emergency response”):
  - Evacuation and sheltering
  - Early relocation
  - Potassium iodide ingestion
- Intermediate phase protective actions:
  - Temporary relocation (i.e., habitation restrictions)
- Long-term phase protective actions:
  - Temporary and permanent relocation (i.e., habitation restrictions)
  - Decontamination
  - Farming restrictions

PROTECTIVE ACTIONS

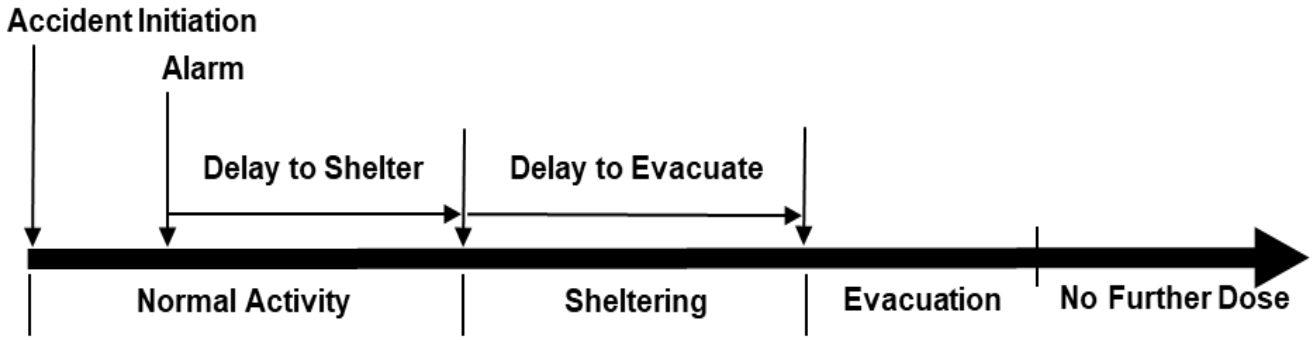
Introduction

- Many protective actions are dose-dependent
  - If a projected dose exceeds a dose criterion during a specified exposure period, it triggers a protective action.
  - Dose projections for relocation are used for the early, intermediate, and long-term phase.
  - Currently, MACCS dose projections assume normal activity.

PROTECTIVE ACTIONS
Early Phase

- Spatial grid is divided into two areas according to the user-specified radial interval (NUMEVA)
  - Inside NUMEVA: Evacuation and sheltering region
  - Outside NUMEVA: Early relocation region
  - When NUMEVA = 0, there is no evacuation or sheltering region (only early relocation)

PROTECTIVE ACTIONS
Evacuation and Sheltering Timeline

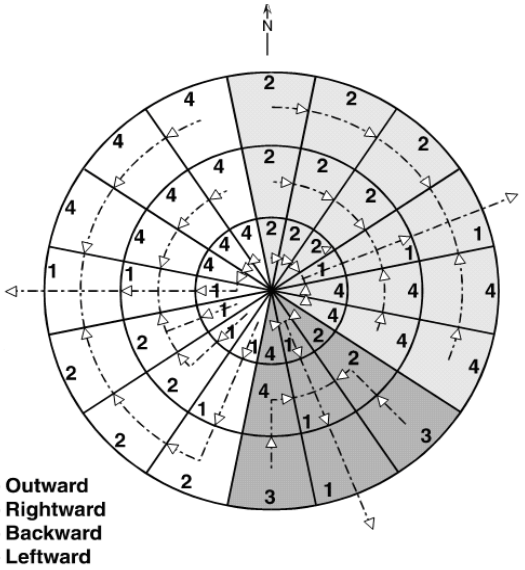


Evacuation and Sheltering Timeline for a Generic Cohort

- Three states of activity based on timeline
  - Normal activity, sheltering, and evacuation
  - Each cohort may be assigned unique activity-specific protection factors and breathing rates

PROTECTIVE ACTIONS
Evacuation Transit and Routing

- Two evacuation routing options (EVATYP = "RADIAL" or "NETWORK")
  - Radial evacuation: Evacuees travel radially outward
  - Network evacuation: Evacuees travel along user-specified grid
- During transit, MACCS models evacuees as moving from spatial grid midpoint to midpoint in a stepwise fashion until they reach the travel boundary (LASMOV)
- MACCS reports doses to an individual according to where the individual originates
- Time spent in each spatial element depends on
  - Grid size
  - Travel speed (ESPEED) for each travel phase
  - Speed multiplier (ESPGRD) for each spatial element
  - Speed multiplier (ESPMUL) for precipitation



Network evacuation direction with corresponding IDIREC values on a spatial grid.

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PROTECTIVE ACTIONS
Early Relocation

- Early relocation is a dose-dependent response that occurs outside the evacuation and sheltering boundary (NUMEVA).
- Projected dose includes early exposure pathways: cloudshine, groundshine, direct and resuspension inhalation (skin deposition doses not included).
- The projected dose is for a single period, which occurs when the first plume arrives.
- Early relocation has two areas, hotspot and normal relocation.
- The user specifies:
  - The early relocation dose criteria (DOSHOT / DOSNRM)
  - The relocation times after plume arrival (TIMHOT / TIMNRM)
  - The dose projection period (DPPEMP)
  - The critical organ (CRIORG)
- Once relocation occurs, displaced individuals receive no dose for the remainder of the early phase (ENDEMP).

PROTECTIVE ACTIONS
Intermediate-Phase Relocation

- Intermediate-phase relocation is a dose-dependent response.
- Projected dose includes late exposure pathways: groundshine and resuspension inhalation (ingestion doses not included).
- The projected dose is for a single period, which occurs at the start of the intermediate phase (ENDEMP). Relocation occurs immediately.
- The user specifies:
  - The intermediate-phase habitability dose criterion (DSCRTI)
  - The dose projection period (DPP_INTPHAS)
  - The critical organ (CRTOCR)
- Displaced individuals receive no dose during intermediate phase period (DUR_INTPHAS).

PROTECTIVE ACTIONS
Long-term Phase

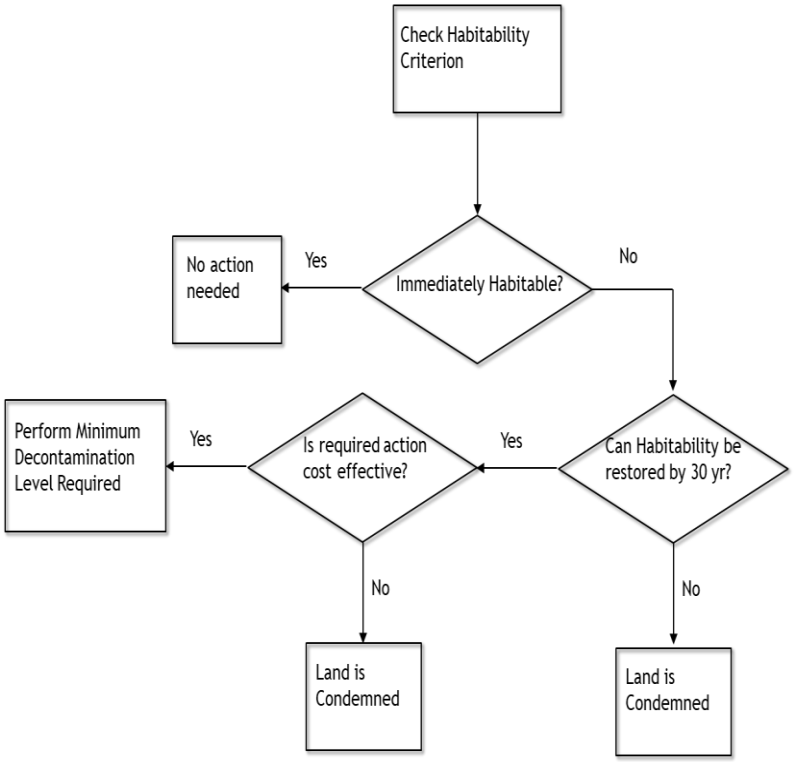
- Land divided into farm and non-farm areas
- Non-farm areas:
  - Habitation restrictions occur when non-farm area exceeds the habitability criterion.
  - The user specifies:
    - The long-term habitability dose criterion (DSCRLT)
    - The dose projection period (TMPACT)
    - The critical organ (CRTOCR)
- Farm areas:
  - Farming restrictions occur in farm areas when food ingestion doses exceed farmability criteria. (The farmability criteria depend on which food chain model the user selects.)
  - Farming restrictions also occur when farmland exceeds the habitability criterion, as MACCS assumes farmland is otherwise not farmable.

PROTECTIVE ACTIONS
Decontamination

- Decontamination reduces groundshine and resuspension inhalation doses.
- Decontamination may occur in both non-farm and farm areas to help restore habitability
- Decontamination does not affect modeled concentration of radioactivity in agricultural products
- User can specify up to three decontamination levels. Each decontamination level requires the user to specify:
  - a dose reduction factor (DSRFCT)
  - a decontamination time (TIMDEC)
  - a decontamination cost (*$/hectare*) for farm areas (CDFRM)
  - a decontamination cost (*$/capita*) for non-farm areas (CDNFRM)

PROTECTIVE ACTIONS
Long-Term Actions for Non-farm Areas

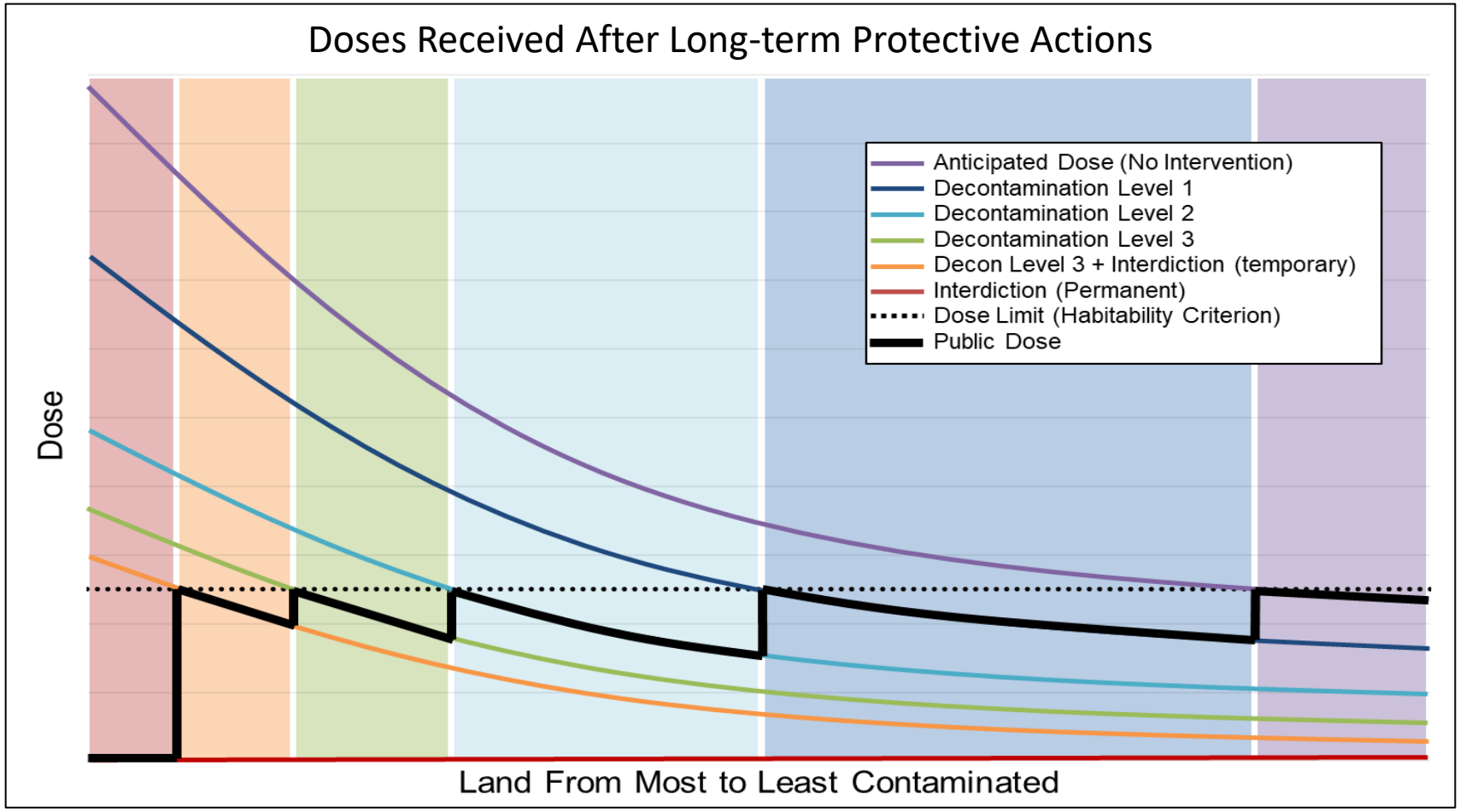
- Relocation at the start of the long-term phase occurs when the ambient dose is projected to exceed the habitability dose criterion
- MACCS determines whether habitability can be restored by evaluating a set of increasingly aggressive protective actions.
- Residents return when the habitability criterion is satisfied by either decontamination or decontamination plus a period of subsequent interdiction.
- Grid elements for which habitability cannot be restored, or for which the restoration of habitability is cost-prohibitive, are permanently condemned and no doses are accrued in the long-term phase



Logic Flowchart for Non-farm Areas

PROTECTIVE ACTIONS

Long-term Non-farm Areas



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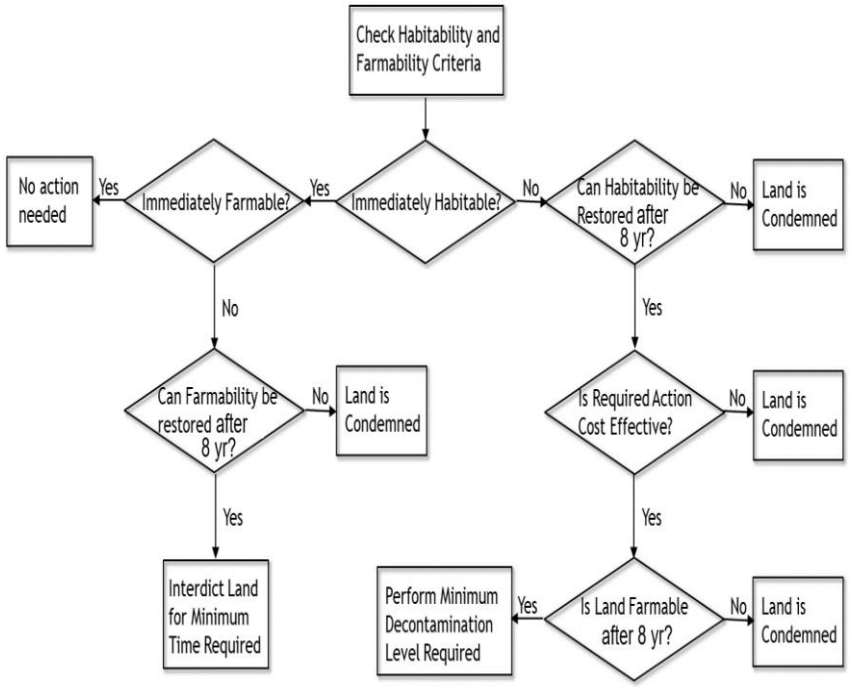
PROTECTIVE ACTIONS
Long-Term Actions for Farm Areas

- Farming restrictions occur beginning at the end of the early phase when either
  - Food ingestion doses exceed farmability criteria, or
  - The ambient dose exceeds the habitability criterion.
- If a farm area is not immediately habitable, it must become habitable before the MACCS considers lifting the long-term farming restrictions.
- If it is not possible to restore farmability, MACCS condemns the farm area and assumes no action is taken to restore habitability.
  - Otherwise, MACCS uses the same process for lifting habitability restrictions in both farm and non-farm areas.
  - Decontamination can occur in farm areas, but only to help restore habitability and only if it is cost effective, just as in non-farm areas.
  - Decontamination does not reduce long-term food ingestion doses or the minimum interdiction period required for farmability.
- Ultimately, the total farm interdiction period is the larger one of two time periods: (1) the minimum farm interdiction period due to farmability criteria, or (2) the habitation restriction period.



Logic Flowchart for Farmland Areas

DOSIMETRY AND PROTECTIVE ACTIONS

QUESTIONS?