SOCIAL AND ECONOMIC IMPACTS

Outline

- Introduction
  - Market impacts
  - Non-market impacts
- Market impacts
  - Evacuation and early relocation costs
  - Intermediate phase relocation costs
  - Long-term costs in non-farm areas
  - Long-term costs in farm areas

SOCIAL AND ECONOMIC IMPACTS

Introduction

- Nuclear accident impacts can be divided into two categories: market and non-market
- Market impacts (sometimes called “financial impacts” or “special damages”) include:
  - Onsite and offsite property damage
  - Economic disruptions
  - Accident-related expenditures
- Non-market impacts (sometimes called “noneconomic impacts” or “general damages”) include:
  - Health effects
  - Societal disruptions
  - Environmental damage

SOCIAL AND ECONOMIC IMPACTS
Market Impacts

- Evacuation and early phase relocation costs
- Intermediate phase relocation costs
- Long-term costs in non-farm areas (*$/capita*)
  - One-time relocation
  - Decontamination (habitation restricted area)
  - Loss of use and property depreciation
- Long-term costs in farm areas (*$/farm-hectare*)
  - Milk and crop disposal
  - Decontamination (habitation restricted area)
  - Loss of use and property depreciation
- Cost models do not consider
  - Onsite damages or disruptions
  - Property losses due to housing market impacts
  - Certain expenditures (e.g., decontamination in habitable areas, removal of condemned structures, cost of litigation and a compensation system, medical expenses)
  - Economic disruptions due to stigma effects (e.g., tourism, trade)

SOCIAL AND ECONOMIC IMPACTS
Non-Market Impacts

- MACCS cost models do not estimate an economic value for non-market impacts.
- MACCS does evaluate important metrics related to non-market impacts, including:
  - the number of cancer fatalities and other health effects
  - the number of displaced individuals
  - the amount of land contamination

ECONOMIC IMPACTS

Evacuation and Early Relocation

Cost of the early protective action CE_i for cohort *i* (for either evacuation or early relocation) is the following:

$$CE_i = CEV \cdot \Delta t_i \cdot POP_i$$

Where

- CE_i is the early protective action cost (*$*) for cohort *i*,
- CEV is the daily per capita cost (*$/person-day*), as specified by the parameter EVACST,
- Δt_i is the duration (*days*) of the protective action for cohort *i*, and
- POP_i is the population of cohort *i*.

Costs accrue for all early relocated population and all evacuees affected by the plume.

Costs are not accrued for evacuees who may immediately return because their residence was unaffected by the plume

ECONOMIC IMPACTS

Intermediate Phase Relocation

The cost of intermediate phase relocation in a spatial element is the following:

$$CI = CIR \cdot \Delta t \cdot POP$$

where

- CI is the cost of intermediate phase relocation ($),
- CIR is the daily per capita cost (*$/person-day*) of intermediate phase relocation per individual, as specified by the parameter RELCST,
- Δt is the duration (*days*) of intermediate phase relocation period, and
- POP is the displaced population (*persons*) of a spatial element due to intermediate phase habitation restrictions.

Costs associated with loss of use and depreciation of property during the intermediate phase are captured in the long-term phase cost estimation

ECONOMIC IMPACTS

Long-Term Costs

In a spatial element, the cost of long-term protective actions is determined as follow:

$$CL = C^{NF} \cdot POP + C^{F} \cdot AF$$

where

- *CL* is the total cost incurred as a result of long-term protective action taken within a given spatial element (*$*),
- C^{NF} is the per capita cost (*$/person*) of long-term protective actions in a non-farm area,
- *POP* is the displaced population (*persons*) from a spatial element due to long-term habitation restrictions,
- C^{F} is the unit cost (*$/hectare*) of long-term protective actions in a farm area, and
- *AF* is the size of the restricted farm area (*hectares*) in the spatial element.

ECONOMIC IMPACTS

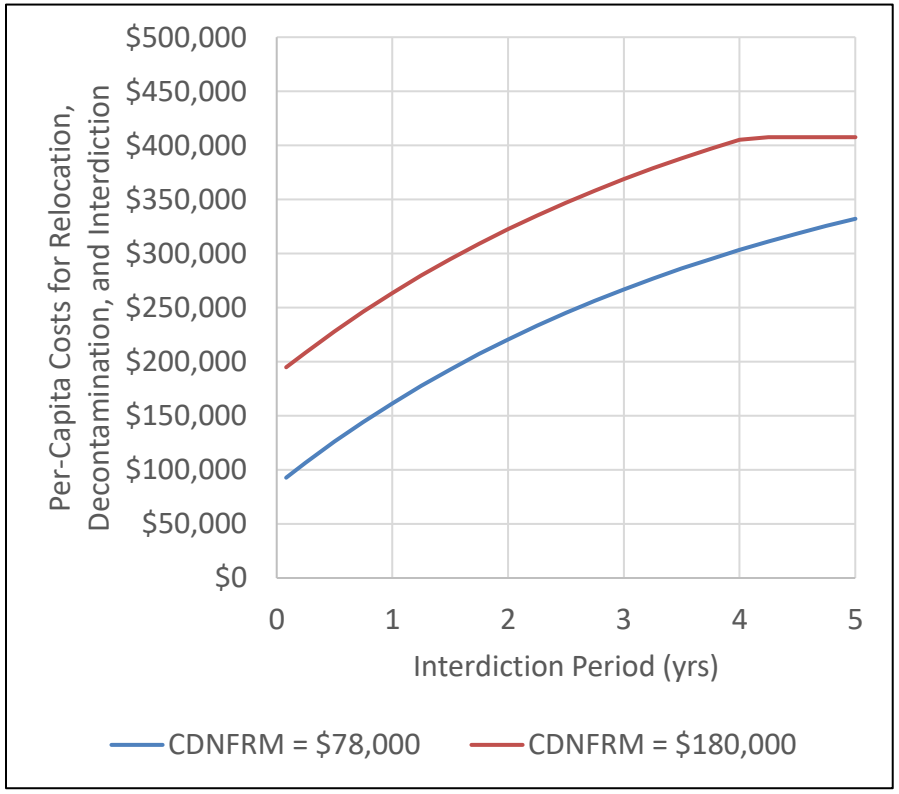
Long-Term Costs in Non-Farm Areas

When the non-farm area in a grid element is subject to temporary restrictions due to habitability limits, the unit cost in the non-farm area of the spatial element is:

$$C^{NF} = CF + CD_{\ell}^{NF} + \left(1 - e^{-rt} \cdot \left[(1 - a^{NF}) + a^{NF} \cdot e^{-dt}\right]\right) \cdot VW^{NF}$$

where

- CF is the per-capita one-time relocation cost (*$/person*).
- CD_{ℓ}^{NF} is the per-capita decontamination cost of the minimum decontamination level ℓ that can restore habitability in non-farm areas (*$/person*),
- VW^{NF} is the per capita value *($/person*) of non-farm wealth in the non-farm area,
- a^{NF} is the regional fraction of wealth (unitless) for non-farm areas that is from land improvements
- d is the depreciation rate (yr^{-1}),
- r is a rate of return (yr^{-1}), and
- t is the interdiction period (*yr*) caused by habitability restrictions in the grid element.



Example of long-term per-capita non-farm losses as a function of length of interdiction period

ECONOMIC IMPACTS

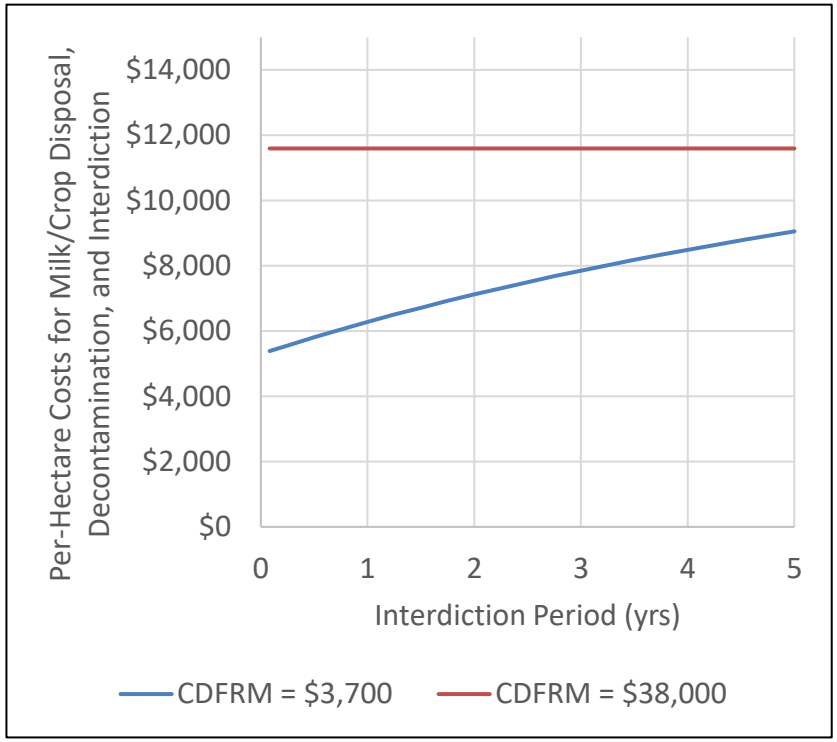
Long-Term Costs in Farm Areas

When the farm area in a grid element is subject to temporary restrictions due to either habitability or farmability limits, whichever is longer, the unit cost in the farm area of the spatial element is:

$$C^F = CMD + CNMD + CD_\ell^F + \left\{1 - e^{-rt} \cdot \left[(1 - \mathrm{a}^F) + \mathrm{a}^F \cdot e^{-dt}\right]\right\} \cdot VW^F$$

where

- CMD is the unit cost of lost milk sales (*$/hectare*),
- $CNMD$ is the unit cost of lost non-milk sales (*$/hectare*),
- CD_ℓ^F is the unit decontamination costs ($) of the minimum decontamination level ℓ that can restore habitability in farm areas (*$/hectare*),
- VW^F is the unit value *($/hectare*) of farm wealth in farm areas,
- a^F is the fraction of the wealth (unitless) for farm areas that is from land improvements,
- d is the depreciation rate (yr^{-1}),
- r is the rate of return on investment (yr^{-1}), and
- t is the interdiction period (*yr*) caused by either habitability or farmability restrictions in the grid element



Example of long-term per-hectare farm losses as a function of length of interdiction period

RADIOGENIC HEALTH EFFECTS

Outline

- Introduction
- Early health effects dose-response model
- Cancer incidence/fatality dose-response model
  - Linear, no threshold
  - Linear quadratic
  - Annual threshold
  - Piecewise linear

RADIOGENIC HEALTH EFFECTS

Introduction

- Health effects from ionizing radiation are broadly categorized into two main categories:
  - Stochastic effects, which include:
    - Cancer incidence / fatality
    - Heritable effects
  - Tissue reactions (i.e., deterministic effects), which include:
    - Early injury / fatality
    - Degenerative conditions (i.e., cataracts, cardiovascular disease, and cerebrovascular disease [ICRP, 2012; NASA, 2016].
- MACCS analyses typically model cancer and early health effects.

RADIOGENIC HEALTH EFFECTS

Early Health Effects

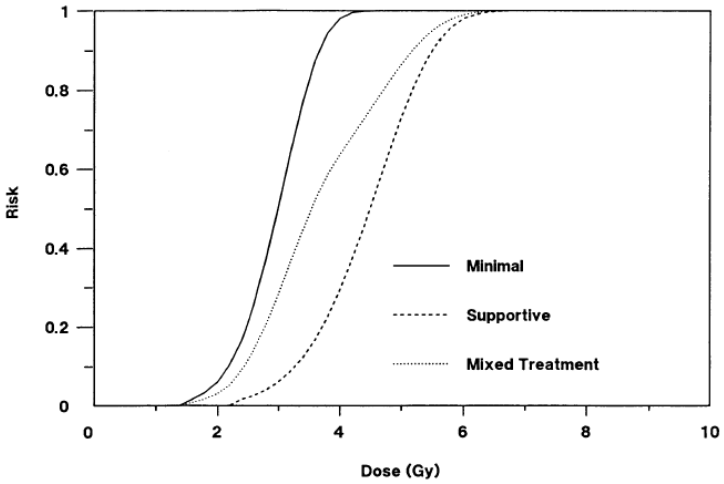
MACCS estimates risk of early health effects (injury or fatality) using a sigmoid dose response model based on a Weibull distribution (Evans 1989):

$$r_k = 1 - exp(-H_k)$$

$$H_k(D_k) = \begin{cases} 0 & D_k < D_{T,k} \\ ln(2) \cdot \left(\frac{D_k}{D_{50,k}}\right)^{\beta_k} & D_k \geq D_{T,k} \end{cases}$$

where

- D_k is the acute dose (*Gy*) to a target organ
- $D_{T,k}$ is the threshold dose (*Gy*)
- $D_{50,k}$ is the acute dose (*Gy*) that would induce an early health effect *k* in half the exposed population, and
- β_k is the shape parameter (dimensionless).



Hematopoietic Syndrome Mortality Risks for Minimal Treatment, Supportive Treatment, and Mixed Treatment - Central Estimates for Exposure at High Dose Rate. (reproduced from Figure 3.1 of Evans 1989)

The early health effect estimates use acute doses, which account for the sparing effect.

Early fatalities are estimated using a "pooled" risk model, i.e.: $H_{EF} = H_R + H_L + H_{GI}$

RADIOGENIC HEALTH EFFECTS

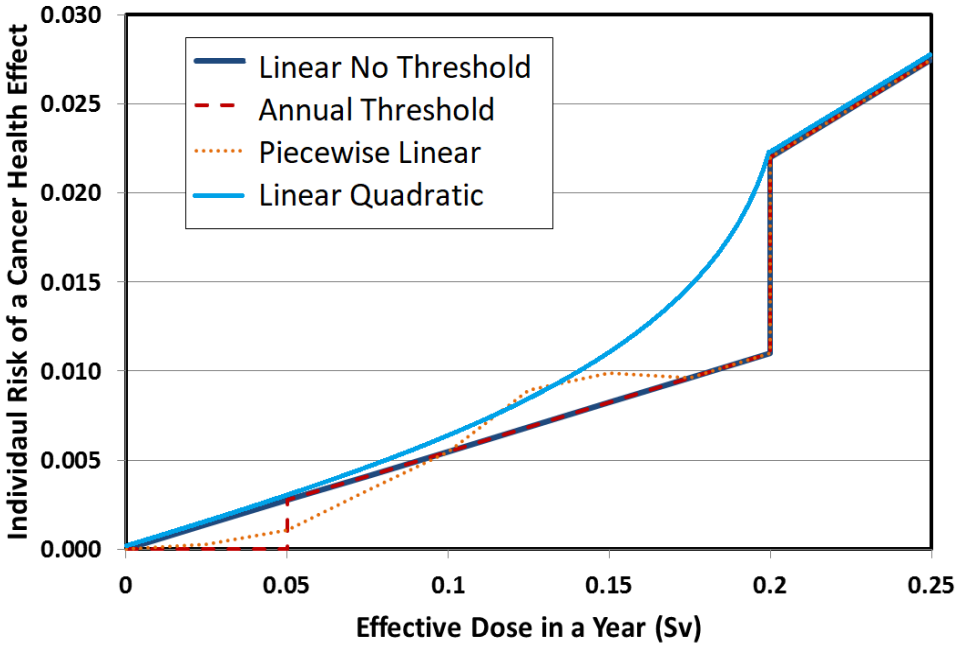
Cancer Incidence/Fatality

Four dose-response models are available in MACCS to calculate cancer incidence and fatalities:

- Linear, no threshold (LNT) with a dose and dose rate effectiveness factor (DDREF)
- Linear quadratic
- Annual threshold
- Piecewise linear

The linear no-threshold and the linear-quadratic models use lifetime doses.

The annual-threshold and piecewise-linear models use annual doses that exceed specified thresholds.



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

RADIOGENIC HEALTH EFFECTS

LNT Model for Cancer Incidence/Fatality

In the LNT dose-response model, the risk r_k^E of stochastic health effect *k* is given by:

$$r_k^E = f_k \cdot RC_k \cdot D_k^E \cdot I_k$$

$$I_k = \begin{cases} 1 & D_k^E \geq D_\alpha \\ \dfrac{1}{\alpha_k} & D_k^E < D_\alpha \end{cases}$$

where

- f_k is the fraction of the population that is susceptible to the risk of health effect k,
- RC_k is the lifetime risk factor (*1/Sv*) of health effect k,
- D_k^E is the early dose (*Sv*) contribution to the lifetime dose
- α_k is the dose and dose-rate effectiveness factor (dimensionless) for health effect k,
- D_α is the dose threshold (*Sv*) of the dose and dose-rate effectiveness factor

Because doses after the early phase are assumed to stay below the low-dose threshold, the dose and dose-rate effectiveness factor α is always applied to long-term (CHRONC) doses

SOCIAL, ECONOMIC, AND HEALTH IMPACTS

QUESTIONS?