Health Canada Santé Canada

Canada

Proposed tool for selecting protective actions in a nuclear emergency: balancing radiological and non-radiological (psychosocial) impacts

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Premise

- Current nuclear emergency response plans are well established and provide clear guidance on radiation dose thresholds for implementing protective actions to minimize radiation doses
- Protective actions that minimize radiation doses may increase the psychosocial impacts to the population (e.g. evacuation and relocation)
- Can we develop a **unit and tool** to compare psychosocial detriment to radiation detriment?
- This tool could help **justify and optimize** evacuation and relocation decisions in a protection strategy

Project Overview - Approach

The project was executed in two phases

Secondary Research: A literature search was conducted to:

1. Identify common psychosocial impacts resulting from nuclear emergencies;
2. Understand the specific drivers of these impacts; and
3. Identify measurement tools used to understand psychosocial impact in a nuclear context.

Decision-Support Tool Development: The decision-support tool was developed using the following steps:

1. Identifying available Canadian data for developing a tool
2. Leveraging the literature to develop a structure for the tool and using quantitative estimates from the literature to quantify potential impacts
3. Building, testing, and reviewing the tool over several iterations

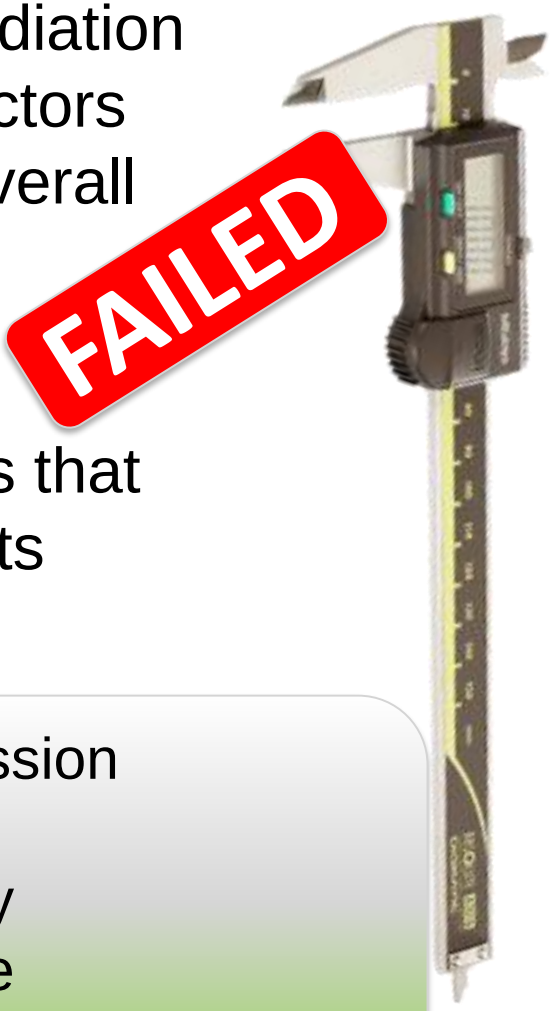
Summary of secondary research review and development of a unit for a non-radiological Sievert

- Literature review identified the main drivers for psychosocial impacts:
  - Residence-related factors
  - Risk perception
  - Socioeconomic changes

- Can we propose a weighting factor for each of these main drivers that contribute to an overall psychosocial detriment?

How to convert psychosocial impacts for comparison to sieverts?

- Weighting factor approach is similar to radiation weighting factors and tissue weighting factors used to generate the sievert – a unit of overall detriment.
- Propose weighting factors for drivers of psychosocial detriment and the outcomes that produce measurable psychosocial impacts



- Residence changes
- Risk Perception
- Socioeconomic changes

- Depression
- PTSD
- Anxiety
- Suicide
- Substance abuse

Data is not available to generate a non-Radiological sievert

- Mental health and psychosocial impacts from nuclear emergencies have been measured with general and summary indicators

- NRC 2021 paper quantifies various non-radiological health effects from evacuations/relocations but specifies that they are **not additive**
- Cannot weight the psychosocial impacts and sum them up to get a sievert-like unit at this time
- Need specific studies on the non-radiological health effects that measure each health effect and their combined impact

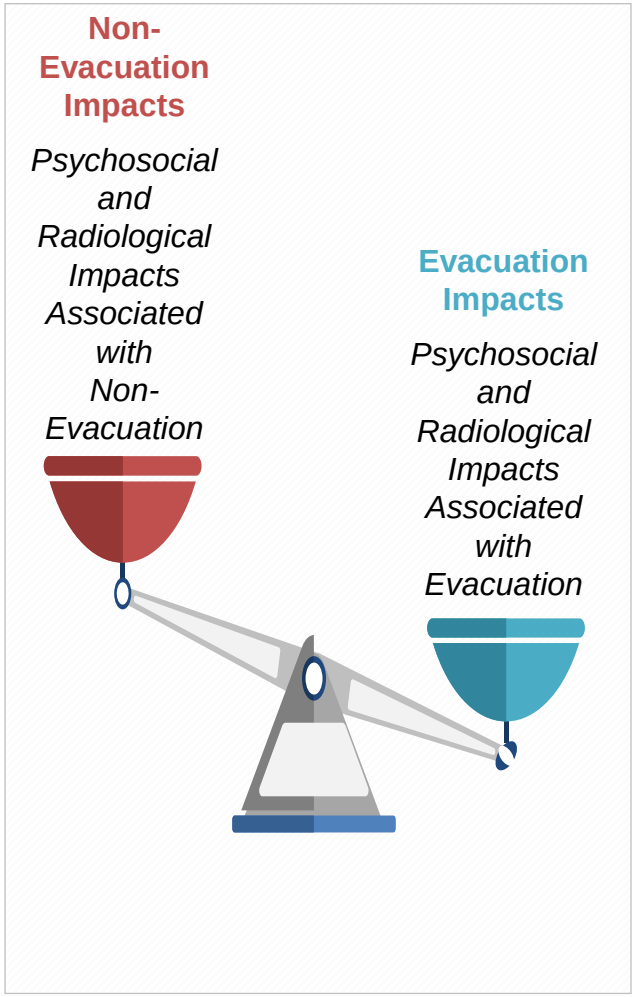
Summary of research results: No significant difference

- A model was used to evaluate the changes in outcomes (psychosocial impacts) between a Canadian population that is affected by the disaster and one that is not.
- Data from the Canadian Community Health Survey (CCHS) was used to evaluate psychosocial impacts that arise from an evacuation from the 2013 Alberta Flood data.
- The variables:
  - **Life Satisfaction**: is used to capture changes in subjective well being from an evacuation. It refers to how satisfied a person feels with their life in general
  - **Time period**: Pre-flood and post-flood
  - **Postal Code**: Captures an individual's proximity to the flood as a proxy for individuals affected by the flood / evacuation
  - **Control variables**: used to control for additional factors that affect life satisfaction. These include socioeconomic controls (e.g. income, education), demographic controls (e.g. gender, age, martial status), and physical/mental disorders (e.g. chronic health conditions, mood/anxiety disorder).

Proof of concept

Non-Evacuation

1. **Psychosocial Costs for Non-Evacuation**
   Anxiety, depression, post-traumatic stress disorder (PTSD), or other psychosocial impacts for a number of reasons (e.g., fear of radiation, potential loss of family members, stress from negative media reporting).
2. **Radiological Cost of Non-Evacuation**
   Radiological harm: Guidance values on projected dose are monetized using the U.S. Nuclear Regulatory Commission's (U.S.NRC) conversion factor



Evacuation

1. **Psychosocial Cost of Evacuation**
   Psychosocial risks including depression, anxiety, and PTSD, as individuals are removed from their communities and their lives are uprooted. The psychosocial impact is captured using an estimate of the prevalence of depression then monetized.
2. **Radiological Cost of Evacuation (OPTIONAL)**
   It is possible that populations experience some radiological harm prior to being evacuated. The decision-support framework captures this cost by monetizing radiological harm using the same methodology applied to the non-evacuation scenario

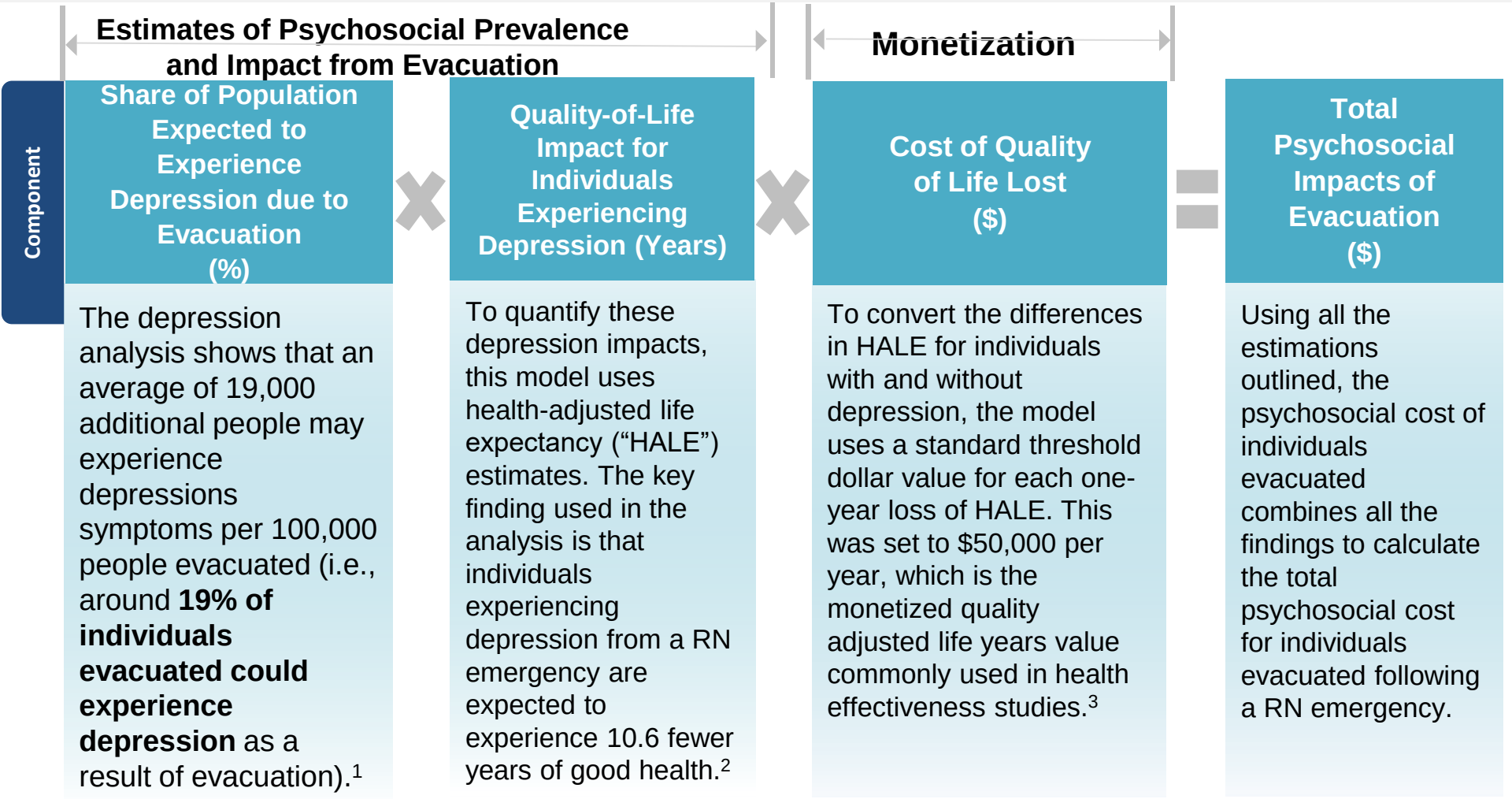
Estimating the Psychosocial Impacts of Non-Evacuation

The psychosocial impact of an RN emergency for non-evacuated populations is captured using an estimate of the impact of an RN emergency on life satisfaction.
The empirical estimates of the life satisfaction impact of an RN emergency are taken from the post-Fukushima Daiichi nuclear power plant accident literature.

Component	Estimates of Life Satisfaction Impacts from a RN Emergency		Monetization		
	Life Satisfaction Impact (Life Satisfaction Points)	×	**Life Satisfaction Monetization ($)**	=	**Total Psychosocial Impacts of Non-Evacuation ($)**
	• The estimated coefficient for life satisfaction impact with respect to proximity to the nuclear power plant is **-0.0816.** • This coefficient means that, in an emergency, a 1-unit increase in proximity (e.g., defined as 3km in the study) to a nuclear plant is associated with life satisfaction being 0.0816 points lower.		• The estimated coefficient for life satisfaction impact with respect to individual income is: 0.3799. • This coefficient indicates that the average income corresponds to +0.3799 life satisfaction points. • We normalize this coefficient to represent the average income required to achieve +1.00 life satisfaction points, which means that 263.23% of average income is associated with life satisfaction being 1.00 points higher.		• Using all the estimations outlined, the psychosocial cost of individuals who are not evacuated is calculated by multiplying the monetized decrease in life satisfaction by the total incomes for the population to calculate the total psychosocial cost for individuals not evacuated following a RN emergency.

Estimating the Psychosocial Impacts of Evacuation

The quantification of the psychosocial impacts in the context of RN emergencies is limited, and summary measures of the psychosocial impact of evacuation at a detailed level were unavailable at the time of research. As such, the model estimates the psychosocial impact for evacuation using four main steps:



1. U.S. NRC (2021)
2. Steensma et al., (2016)
3. Canadian Agency for Drugs and Technologies in Health (CADTH)

Accounting for Radiological Impacts

Based on the sievert reference levels from ICRP and the USNRC monetization of the radiological consequences associated with exposure, this model estimates the monetized detriment for each population group around a nuclear facility. To note, the model currently assumes that individuals who are evacuated are not exposed to radiation.[1] The monetized detriment is a function of:

	Estimates of FSA Radiological Exposure		Monetization	
Component	Projected Dose (Millisieverts)	Total Population Within a Given FSA	The Monetization of Exposure ($)	Total Monetized Detriment
	The projected dose is a function of distance to the power plant. Following current guidance, the estimated millisieverts in the case study model is set at **100 for distances less than 20 kms** from the nuclear power plant.	The larger a population within a given FSA, the larger the total radiological impact.	The model relies on 2014 dollar-per-rem estimates from the U.S. NRC to monetize the health-related consequences associated with radiological exposure • These estimates are based on the value of a statistical life and a nominal risk coefficient for stochastic health effects from radiation exposure.[2]	Multiplying these components together provides an estimate of the radiological impact for a given FSA

1. This is a simplifying assumption; however, with additional information from Health Canada or from a real RN emergency, this assumption can be adjusted.
2. In the context of this model, three steps were required to update the U.S. NRC estimates. First, the value of a statistical life provided by the Treasury Board of Canada Secretariat was inflated to the relevant year of analysis (i.e., 2020). Second, the value of a statistical life was multiplied by the nominal risk coefficient provided by the U.S. NRC to obtain per person-rems. Finally, per-person-rem units were converted to millisieverts using the relationship that 1 rem is equivalent to 10 millisieverts.

Approach to Comparing Psychosocial and Radiological Costs

The net evacuation cost per person compares the total costs (i.e., radiological and psychosocial) of evacuation and non-evacuation for a given population group

The **net evacuation impact** subtracts the total cost (i.e., psychosocial and radiological) of evacuation from the total cost of non-evacuation and divides these costs by the total population within the relevant geographic area.

Cost of Non-Evacuation

- Total Psychosocial Impacts of Non-Evacuation ($)
- \+
- Total Monetized Detriment for individuals Not-Evacuated

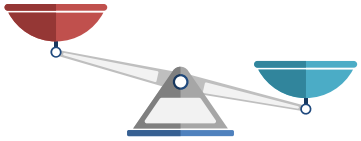
−

Cost of Evacuation

- Total Psychosocial Impacts of Evacuation ($)
- \+
- Total Monetized Detriment for individuals Evacuated

=

Net Evacuation Impact



*If **positive**, non-evacuation costs are greater than evacuation costs. If **negative**, non-evacuation costs are less than evacuation costs.*

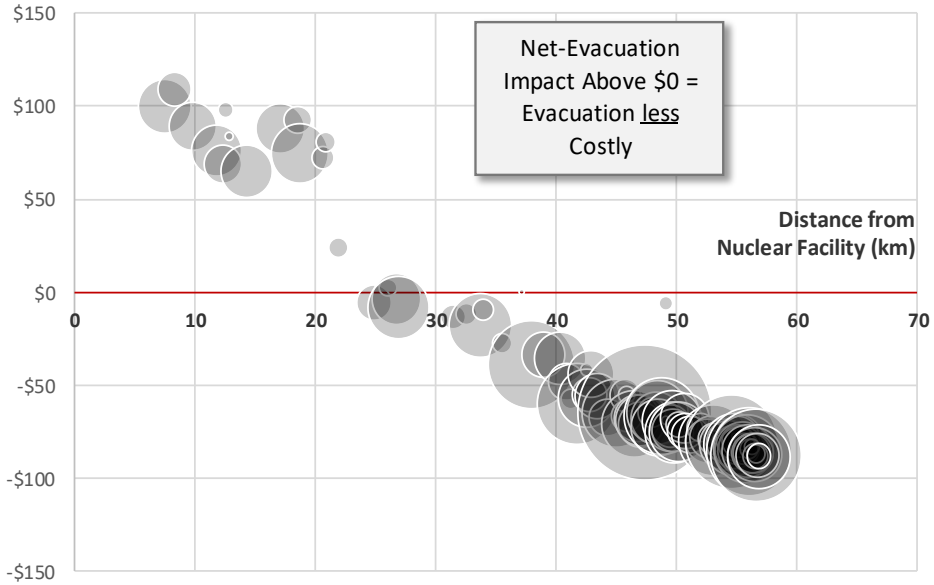
Results

When model inputs are set to their guidance levels, the results show that evacuation is less costly for 15 out of 97 FSAs within a 57-kilometer radius to the nuclear facility, or 12.3% of the population within that radius

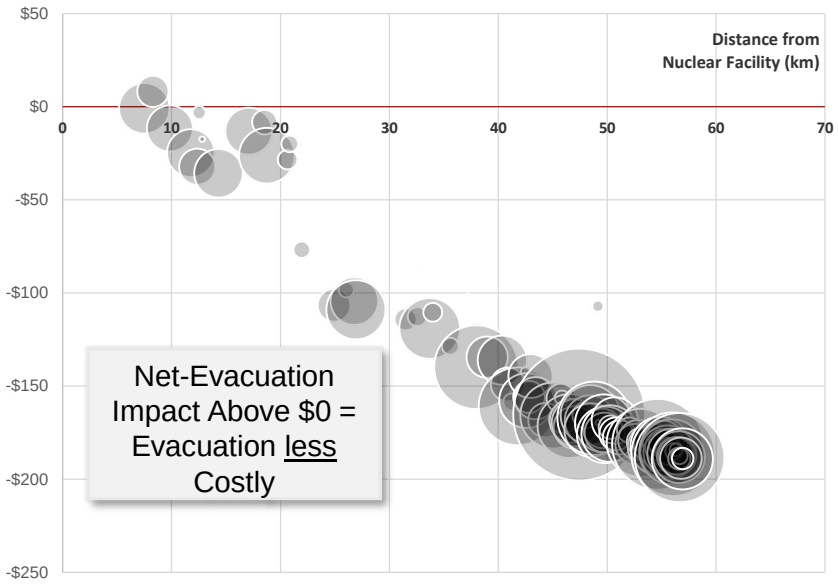
Net Evacuation Impact for Each Forward Sortation Level

Net-Evacuation Impact Per Person [$000s]
Bubble Area = Population Size

Net-Evacuation Impact Per Person for Each Forward Sortation Area (QALY 50k)



Net-Evacuation Impact Per Person for Each Forward Sortation Area (QALY 100k)



Impact of Key Model Parameters on Net-Evacuation Cost (1/2)

Changing the model's key parameters will impact the relative cost of evacuation and non-evacuation

Life Satisfaction: The estimated change in life satisfaction associated with a nuclear emergency for individuals not evacuated. Note, this parameter is negative in this context. Hence, an increase refers to a smaller negative number and a decrease refers to a greater negative number.

An **Increase** in Life Satisfaction post-RN emergency (or more specifically, a smaller loss of life satisfaction) → *Leads to* → A **decrease** in the cost of **non-evacuation**

Depression Prevalence: Depression prevalence is the main variable driving the psychosocial impact of evacuation. It is the estimated share of individuals expected to experience depression from evacuation.

An **Increase** in the number of individuals expected to experience depression due to evacuation… → *Leads to* → An **Increase** in the cost of **evacuation**

Monetary Value of a QALY: The estimated willingness to pay for a full year of life, which enters the model as a negative cost associated with lost quality of life for depression.

An **Increase** in monetary value of a QALY… → *Leads to* → An **Increase** in the cost of **evacuation**

Change in Net-Evacuation Impact

A **decrease** in the net-evacuation impact of evacuation, **implying that evacuation is now relatively more costly**

A **decrease** in the net evacuation impact, **implying that evacuation is now relatively more costly**

A **decrease** in the net evacuation impact, **implying that evacuation is now relatively more costly**

Impact of Key Model Parameters on Net-Evacuation Cost (2/2)

Changing the model's key parameters will impact the relative cost of evacuation and non-evacuation

Income: The total income of income recipients in an FSA divided by the total population.

An **Increase** in income per person impacted by the emergency…

Leads to

An **Increase** in the cost of **non-evacuation**

Leads to

Projected Dose: The effective or equivalent radiation dose that would be expected to be received if protective actions were not taken.

An **Increase** in the effective dose…

Leads to

An **Increase** in the cost of **non-evacuation**

Leads to

Change in Net-Evacuation Impact

An **increase** in the net evacuation impact, **implying that evacuation is now relatively less costly**

An **increase** in the net evacuation impact, **implying that evacuation is now relatively less costly**

Preliminary Results – Sensitivity Analysis

When using the upper and lower bounds of the life satisfaction impact estimate, this yields evacuation estimates in the range of 11.7% to 20% of the population; the range of outcomes for depression prevalence is narrower

A sensitivity analysis was performed on the net-evacuation impacts per person for the life satisfaction and depression prevalence parameters.

Life Satisfaction:

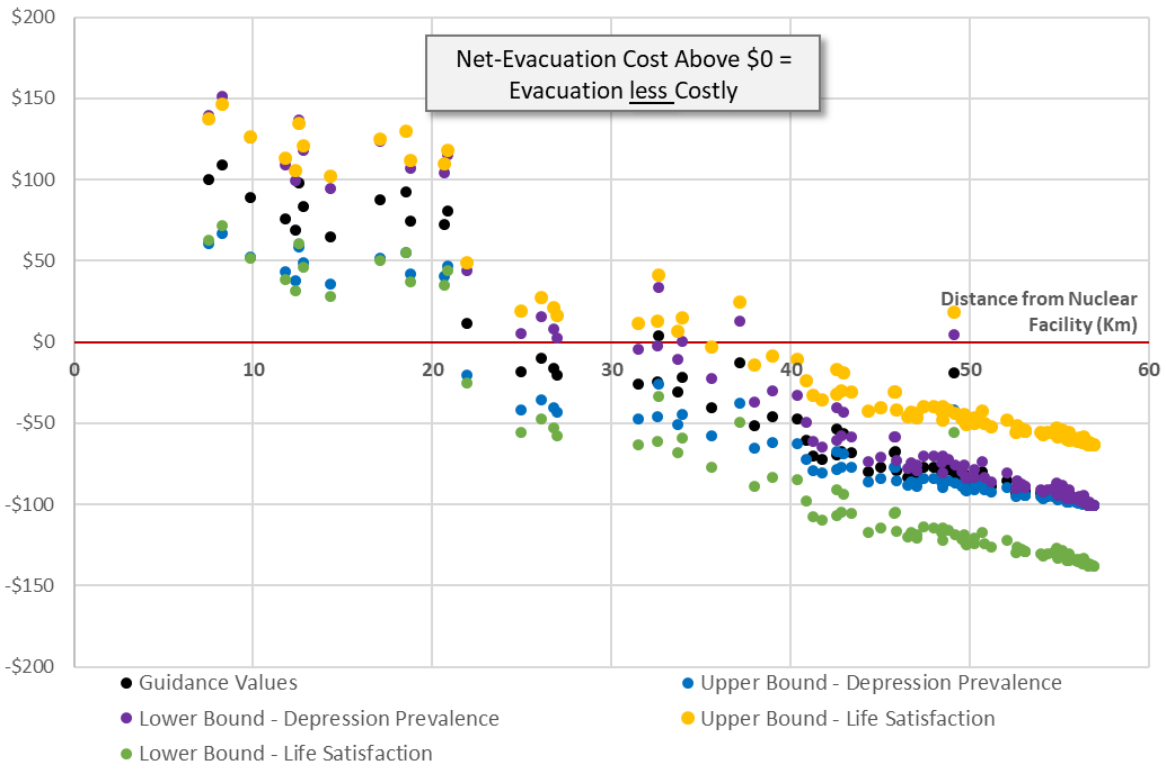
- When using the **upper bound** of life satisfaction (i.e., a higher loss of life satisfaction), it is less costly to evacuate roughly **20.0%** of the population within 57 kilometres.
- When using the **lower bound** estimate of life satisfaction (i.e., a lower loss of life satisfaction for individuals not evacuated), it is less costly to evacuate roughly **11.7%** of the population.

Depression Prevalence:

- When using the **upper bound** (i.e., higher depression prevalence), it is less costly to evacuate approximately **11.7%** of the population.
- On the other hand, it is less costly to evacuate **17.3%** of the population within 57 kilometres when using the **lower bound** of depression prevalence.

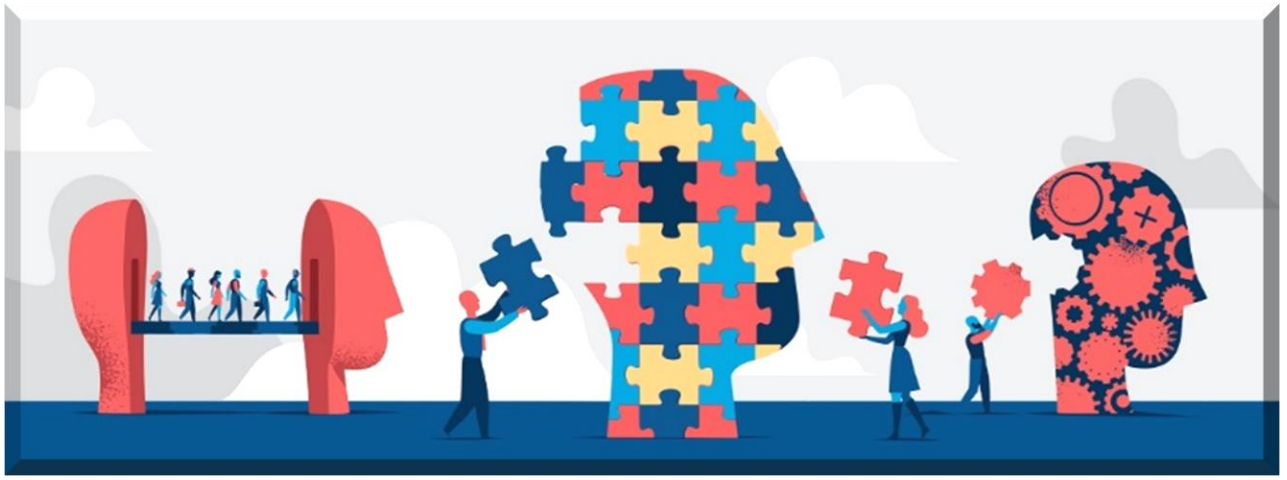
Net Evacuation Impact – Sensitivity Analysis

Net-Evacuation Impact Per Person [$000s]



What can we do with the tool as is?

- Proof of concept for a decision tool to balance radiological and psychosocial detriment
- Contribution to evidence-based guidance on a justified and optimised protection strategy that considers psychosocial impacts
- Improved risk communications tools



Summary for discussion

- The development of a non-radiological sievert for psychosocial detriment from protective actions requires future research
- Psychosocial impacts measured with general and summary indicators are interrelated and cannot be summed
- Individual psychosocial impacts can be measured and compared to radiological impacts
- A single measured psychosocial impact (depression) can have a very significant impact
- These tools are needed to justify and optimize decision making in nuclear emergencies
- What needs to be added/improved so that this tool could be implemented?