Application of Resilience Metrics to Nuclear Accident Consequence Assessment

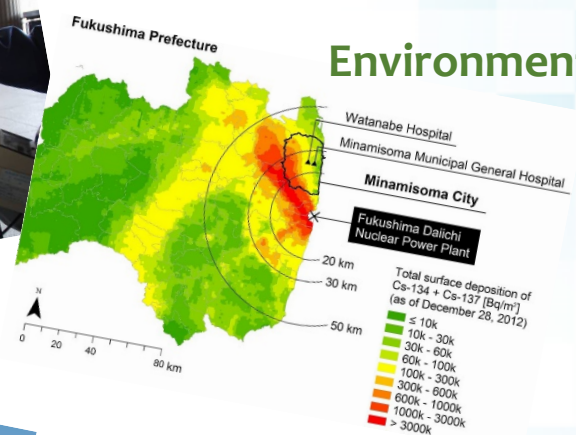
Kampanart SILVA (Ph.D.)*
Senior Nuclear Scientist, Nuclear R&D Division

Wasin Vechgama
Nuclear Engineer, Nuclear R&D Division

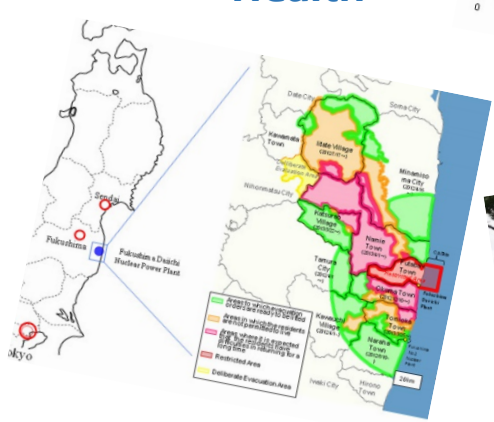
สถาบันเทคโนโลยีนิวเคลียร์แห่งชาติ (องค์การมหาชน)
Thailand Institute of Nuclear Technology (Public Organization)

Fukushima Daiichi NPP Accident

Health



Environment



Economics

Society

Nuclear Accident Consequence Index

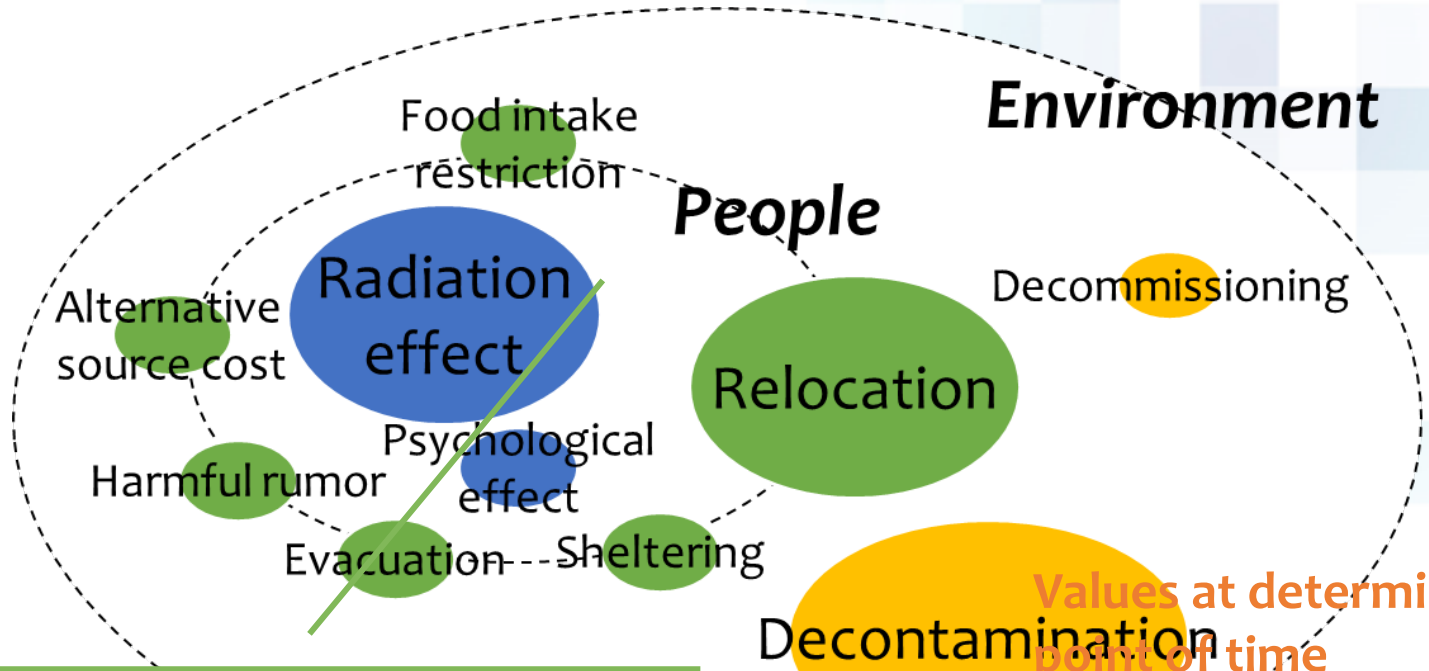
NACI

Whole picture of accident consequences at a glance

1 https://www.japantimes.co.jp/
2 https://bmjopen.bmj.com/
3 http://www.reconstruction.go.jp/
4 https://www.npr.org/

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Nuclear Accident Consequence Index
NACI



A year of relocation of 100,000 people
VS
10 years of relocation of 10,000 people

Values at determined point of time
→ Cannot capture time-dependent features

K. Silva, K. Okamoto. "A simple assessment scheme for severe accident consequences using release parameters", Nuclear Engineering and Design, 305, pp. 688-696, (2016).

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Resilience

Ability of an entity to bounce back

Resilience metrics

Used to assess resilience of the system

Original state → disrupted state → recovered state

NACI ⇔ Resilience Metrics

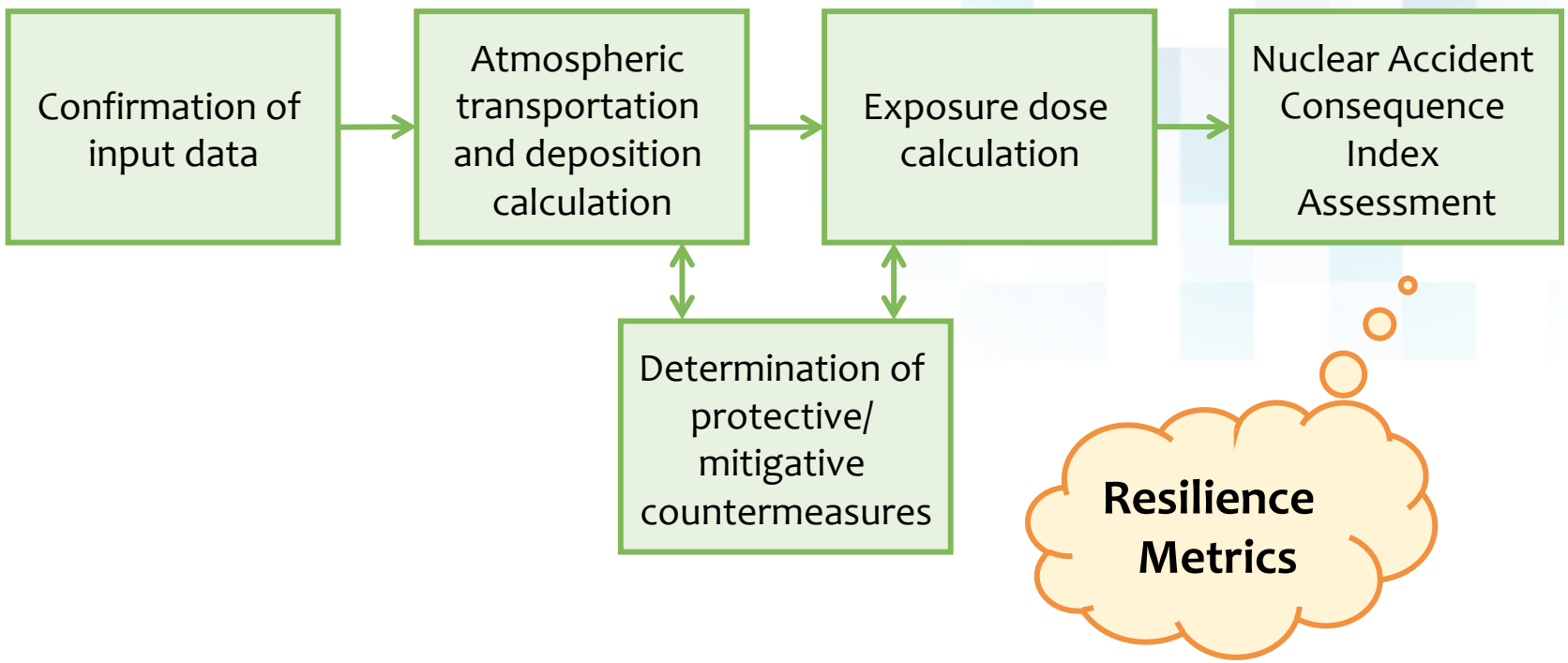
Capture changes of accident consequences with time

Objective

"Apply resilience metrics to nuclear accident consequence assessment"

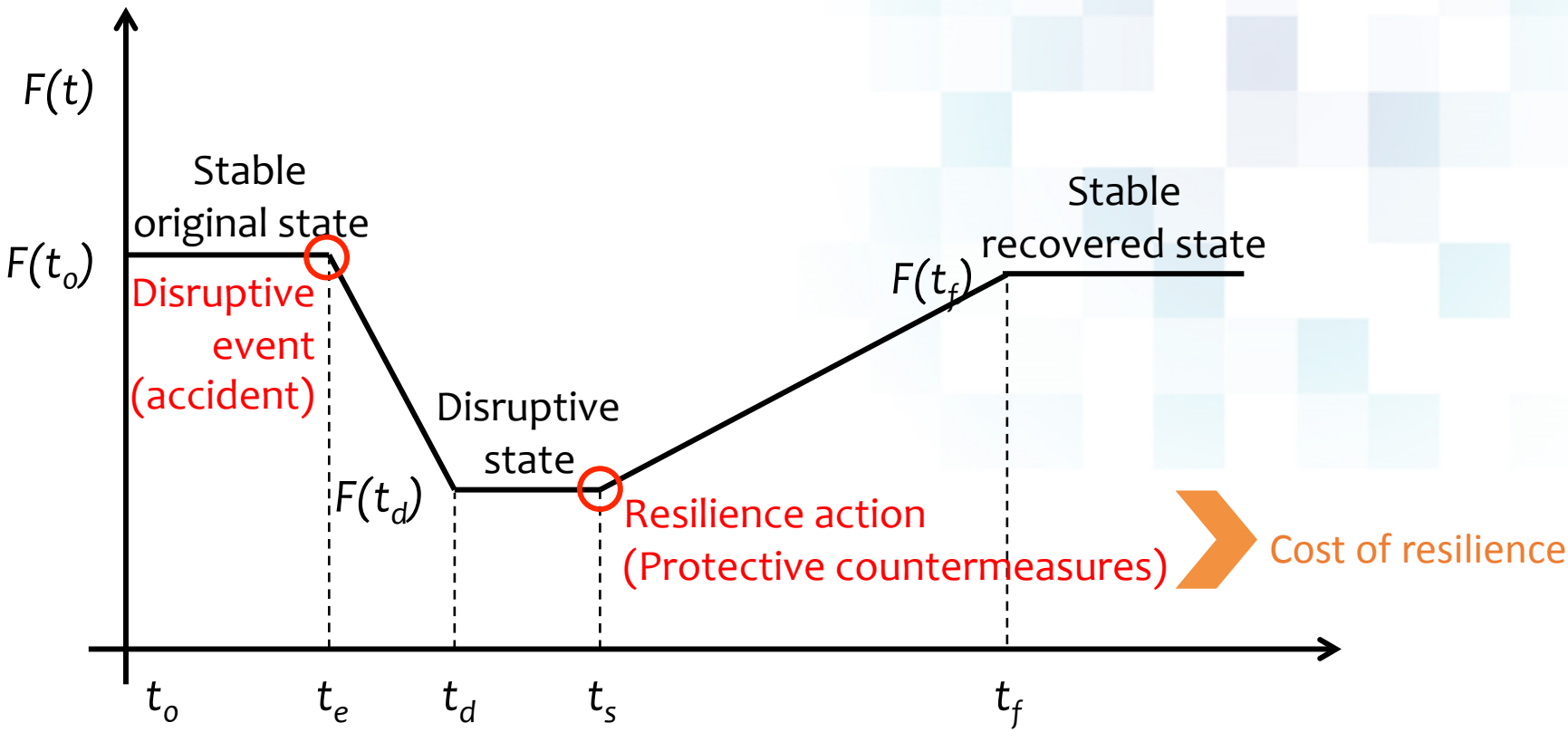
Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Nuclear ACcident Consequence Assessment Code
NACCA



Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Resilience Metrics



D. Henry, J. E. Ramirez-Marquez. "Generic metrics and quantitative approaches for system resilience as a function of time", Reliability Engineering and System Safety, 99, pp. 114-122, (2012).

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Figures-of-Merit and Resilience Actions

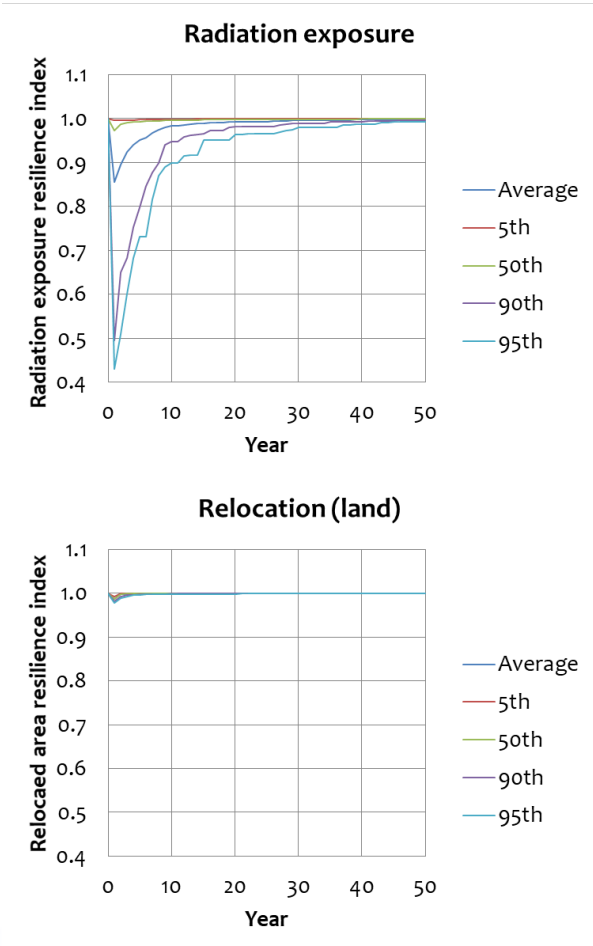
Figures-of-merit (F(t))	**Resilience actions**
Number of people being exposed to radiation dose over prescribed dose limit	Relocation, decontamination
Number of relocated people	Decontamination
Size of relocated area	Decontamination
Size of contaminated area	Decontamination

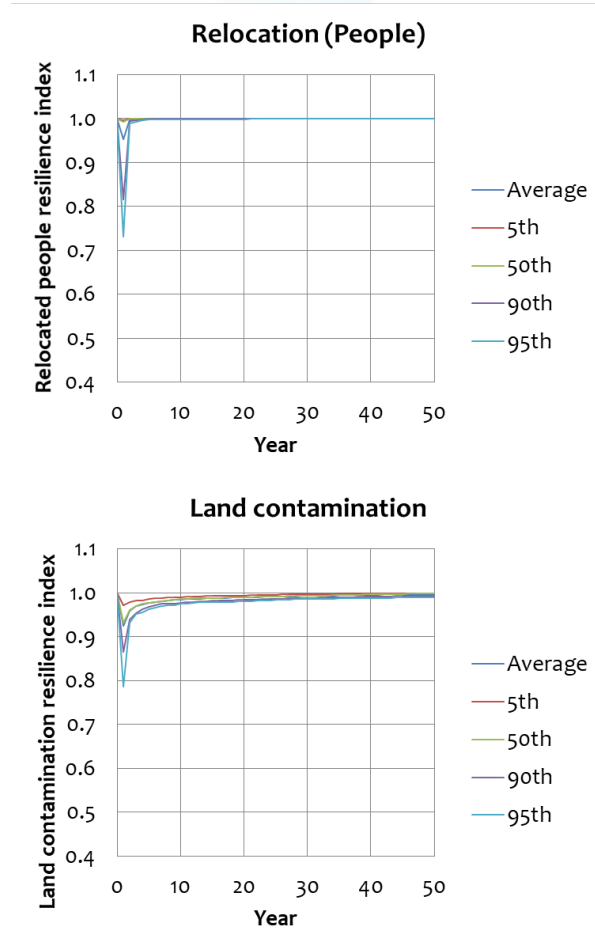
Calculation Conditions

Items	Conditions
Reactor type	1,100 MWe BWR-5
Release location	Headquarters of Thailand Institute of Nuclear Technology
Hypothetical accident	Long-term station blackout
Coverage of meteorological, population, land use and economic data	Within the radius of 200 km from the release point
Meteorological data type	Hourly wind speed, wind direction, precipitation, weather stability of 2014
Meteorological sampling method	Random sampling (100 samples)
Decontamination methods	Based on methods used in Chernobyl and 1FNPS accidents
Dose limit	1 mSv/year
Relocation initiation dose	20 mSv/year
Relocation lifting dose	20 mSv/year

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Similarity among Four Figures-of-Merit





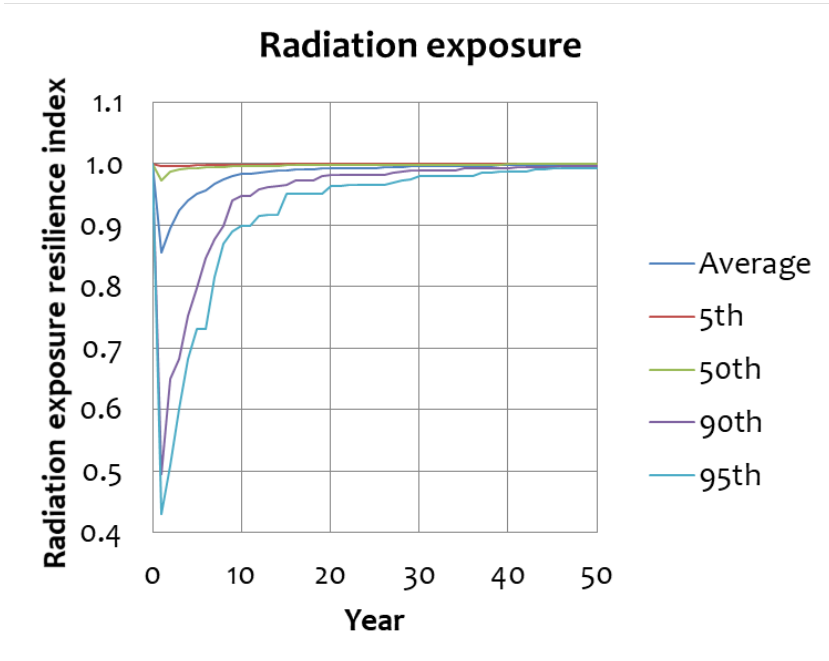
- Sharp decrease

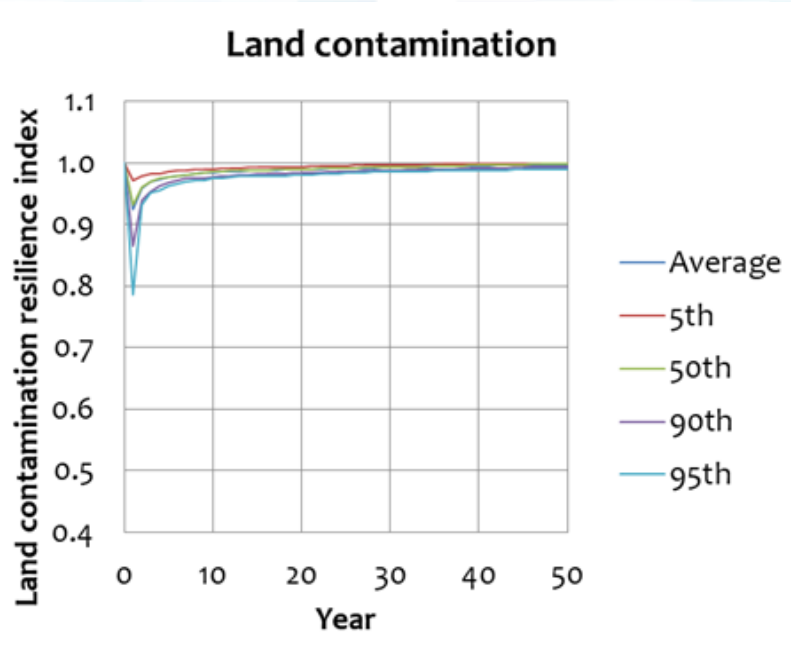
- Large difference among percentile values – effects of weather conditions

- None of them return to original state

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Radiation Exposure VS Land Contamination

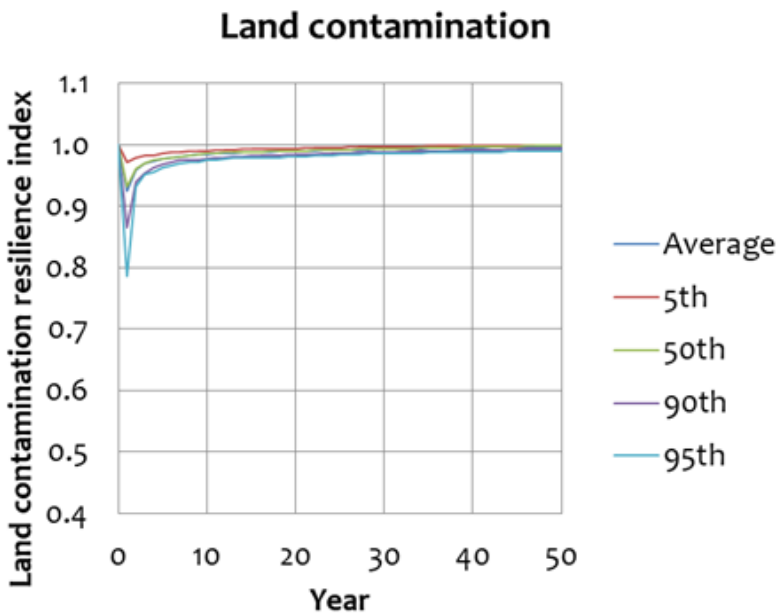


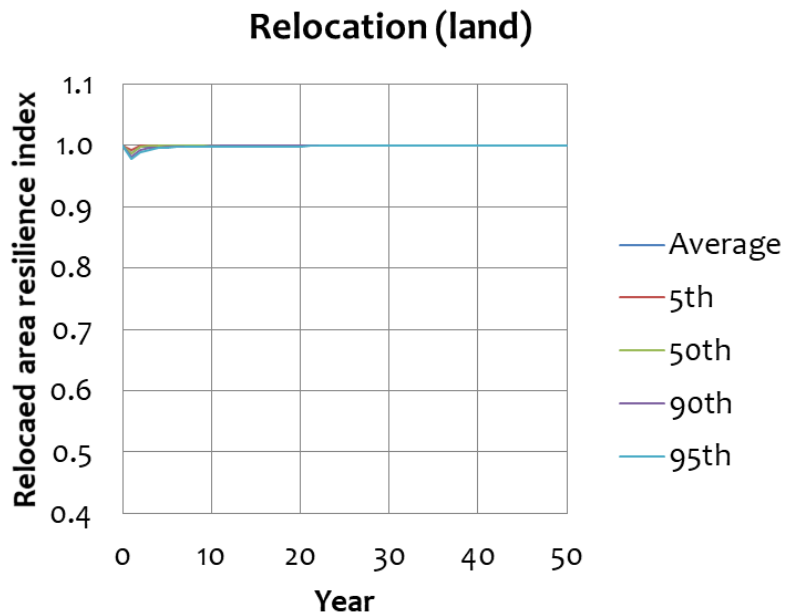


- Criterion for both figures-of-merit is 1 mSv/year
- Sharper decrease in radiation at high percentile values
- Bias in population distribution (large cities 50-80 km from release point)

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Land Contamination VS Relocation

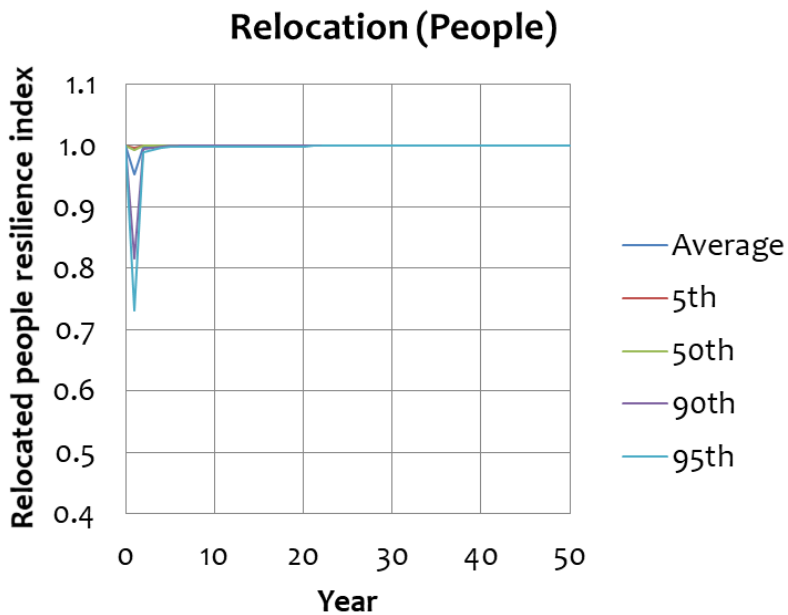


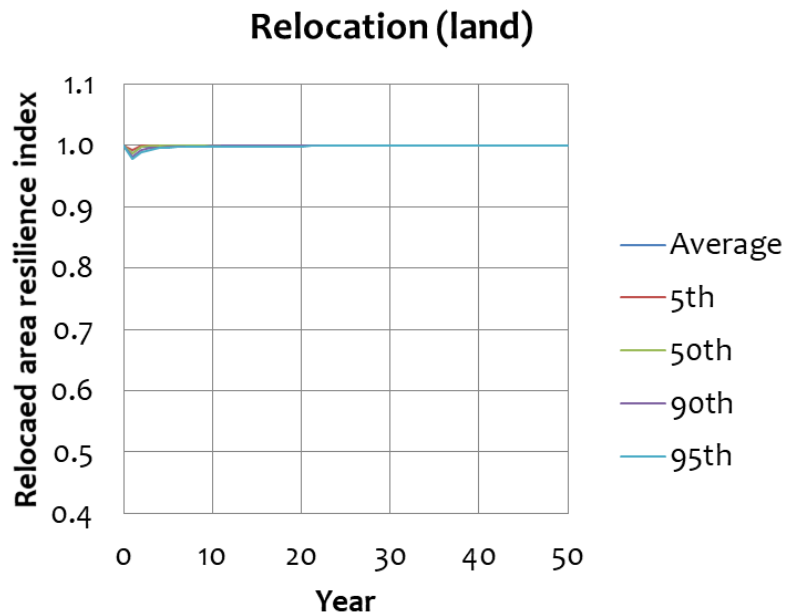


- Land contamination > relocation
- Land contamination: 1 mSv/year
- Relocation: 20 mSv/year (both initiating and lifting doses)

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Relocation – People VS Land

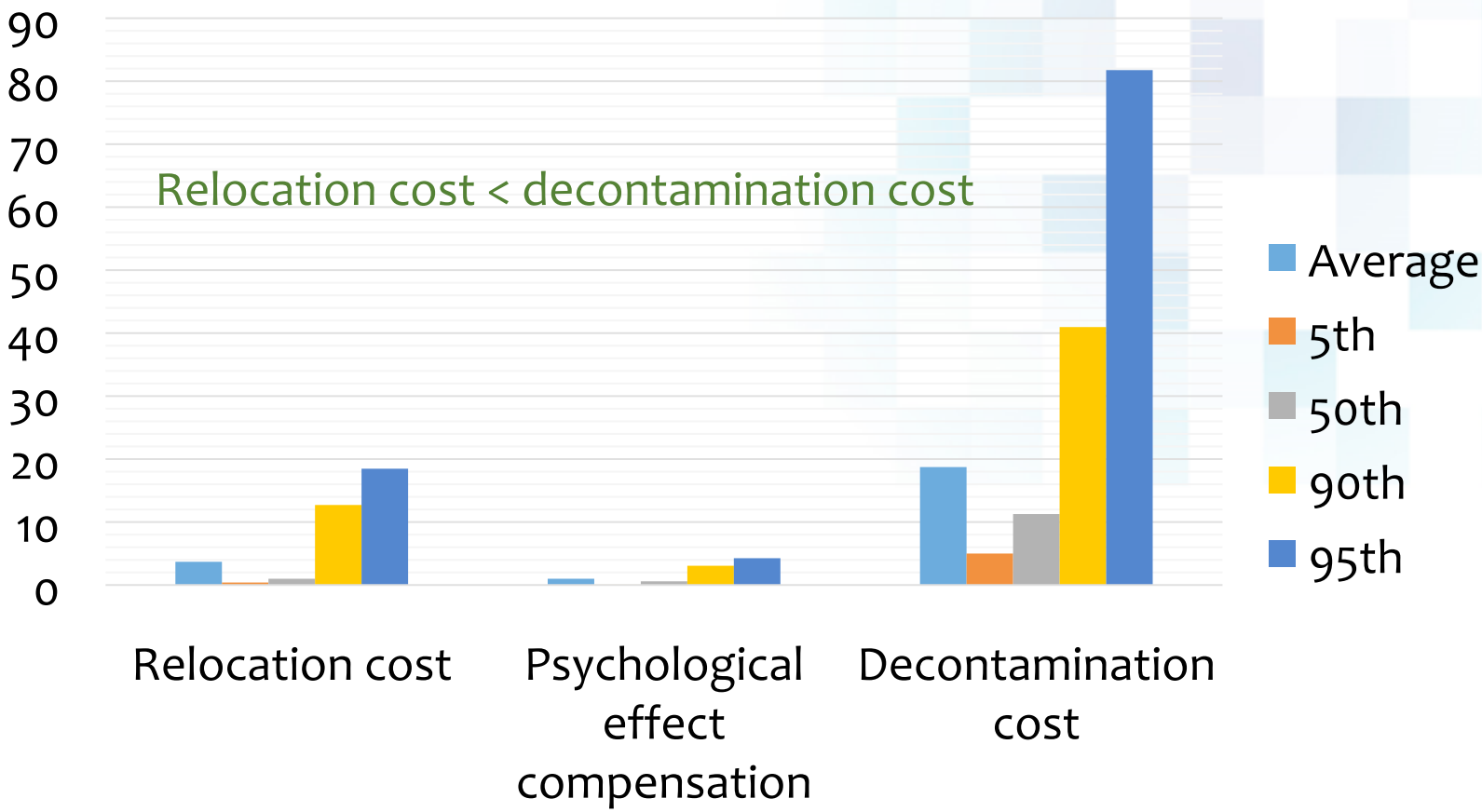




- Criterion for both figures-of-merit is 20 mSv/year
- Sharper decrease in people at high percentile values
- Bias in population distribution (large cities 50-80 km from release point)

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Cost of Resilience



Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Conclusions

Resilience metrics were applied to nuclear accident consequence assessment.

- ***Time-dependent characteristics*** of accident consequences were revealed.
- None of resilience indices returned to the stable original state.
- ***Bias in population distribution*** significantly affects resilience indices related to people → need to have separate resilience indices for people and area.
- ***Extreme weather conditions*** can lead to significant reduction of resilience → need to apply various weather conditions.
- Costs attributed to relocation are much lower than decontamination cost ← lower dose criterion for decontamination (1 mSv/year), comparing to the dose criterion for relocation (20 mSv/year).

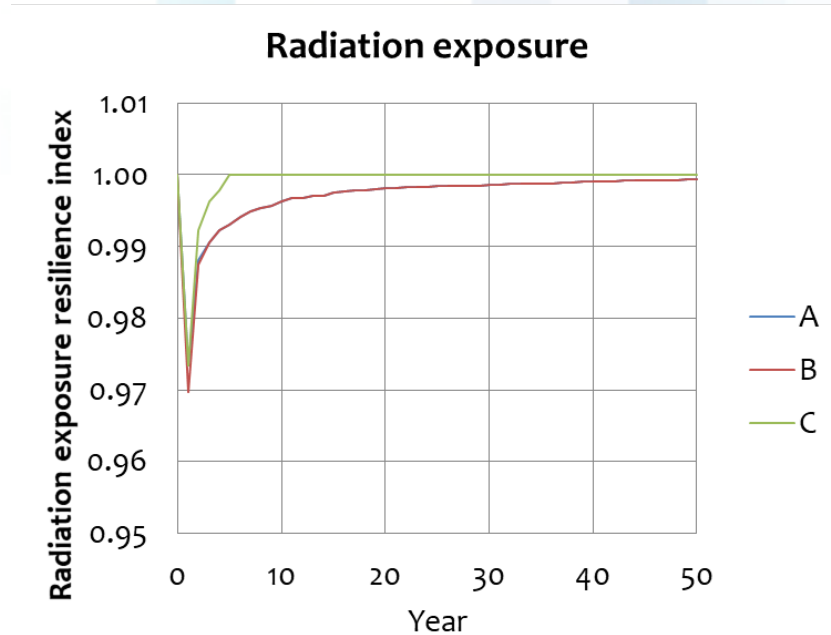
Note that ***protective/mitigative countermeasures*** can vary and may affect the resilience indices.

Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

Further Study

- Explore the changes of figures-of-merit at different conditions.

Conditions	A	B	C
Relocation initiation dose [mSv/y]	20	100	20
Relocation lifting dose [mSv/y]	20	20	1
Dose limit [mSv/y]	1	1	1



Thailand Institute of Nuclear Technology (Public Organization)
9/9 moo 7, Sai Moon, Ongkharak, Nakorn Nayok 26120
Tel. : +66 3739 2901 (to 6) Fax : +66 3739 2913 www.tint.or.th

สถาบันเทคโนโลยีนิวเคลียร์แห่งชาติ (องค์การมหาชน)
Thailand Institute of Nuclear Technology (Public Organization)

Kampanart SILVA
kampanarts@tint.or.th

Wasin Vechgama
wasin@tint.or.th