Cost per Severe Accident as an Indicator for Severe Accident Consequence Assessment

- Proposal on Scope Enlargement of Accident Consequence Assessment Incorporating Lessons Learned from the Fukushima Accident -

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- **Education**
  - 2003 – 2006 Tokyo Gakugei High School, Japan
  - 2006 – 2010 **B.E.** from Department of System Innovation,
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    Faculty of Engineering, The University of Tokyo
  - 2010 – 2012 **M.E.** from Department of Nuclear Engineering & Management
    School of Engineering, The University of Tokyo
  - 2013 – Now **Working for Ph.D.** at Department of Nuclear Engineering & Management
    School of Engineering, The University of Tokyo
    Under JSPS Ronpaku Program
- **Expertise**
  - Nuclear severe accident consequence assessment
  - Probabilistic risk assessment
  - Thermal hydraulics in nuclear power plant
- **Recent work**
  - Cost per severe accident as a index for severe accident consequence assessment
  - Modification of decontamination model for severe accident consequence assessment
  - Sustainability assessment of the generation IV and generation III+ reactors
  - Modification of neutron radiography facility in TRR-1/M1

Why do we need to enlarge the scope of consequence assessment?

Fukushima Accident

Consequences of Severe Accidents

Health Effects

Economic Impacts

Environmental Impacts

Social Impacts

Conversion Factor

A more comprehensive index

Why cost per severe accident?

Cost per Severe Accident

- Can cover a large scope of consequences of severe accidents
  - A number of studies and reports to be referred to[1-3]
- Easy to be understood
  - General public can judge the extent of the consequence by the index
- Cost per severe accident ≠ Actual damage cost

1 Hirschberg S, Spiekerman G, Dones R. Severe accidents in the energy sector. First edition. Project GaBE: comprehensive assessment of energy systems. PSI Bericht Nr. 98-16. Switzerland: Paul Scherrer Institut; 1998.
2 Park S-J. Estimates of the economic consequences of a severe nuclear accident in Japan. J Natl Econ 2005;191(3):1–15.
3 The Commission of Management and Financial Survey of TEPCO. Commission report. Tokyo; 2011.

Objective

“To estimate the cost per severe accident of the anticipated severe accidents in a virtual nuclear reactor in order to assess the consequence of those severe accidents.”

Components of Cost per Severe Accident

Health effects

- ✓ Radiation effect cost
- ✓ Psychological effect cost

Social impacts

- ✓ Harmful rumors

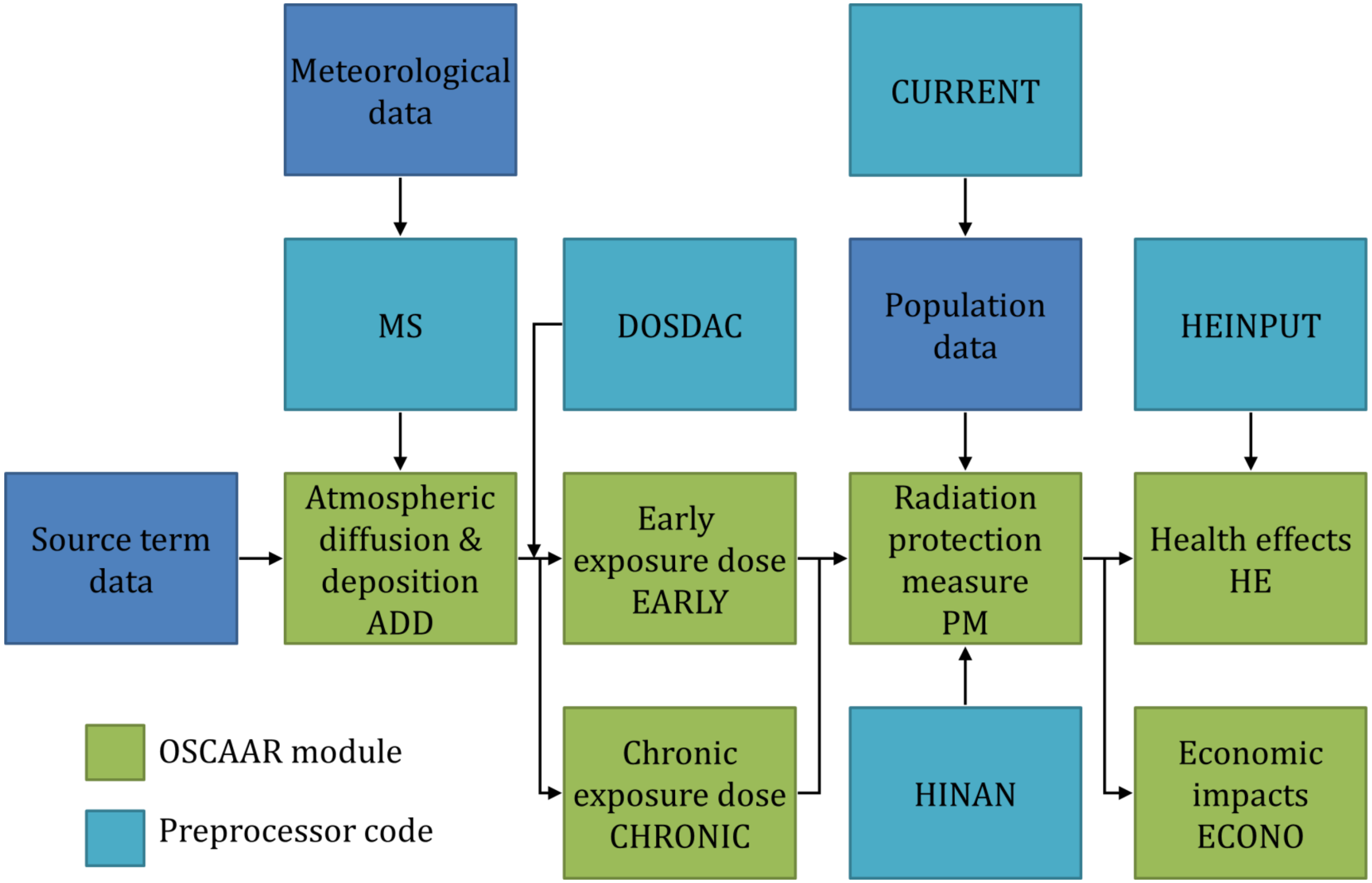
Economic impacts

- ✓ Sheltering cost
- ✓ Evacuation cost
- ✓ Relocation cost
- ✓ Food intake restriction cost
- ✓ Alternative source cost

Environmental impacts

- ✓ Decommissioning cost
- ✓ Decontamination cost

OSCAAR (Off-Site Consequence Analysis code for Atmospheric Releases in reactor accidents)



Calculation flow of OSCAAR

Calculation Conditions and Input Data for OSCAAR

- BWR-5 Plant[1]
  - Target Plant : 1,100 MWe BWR-5 model plant
  - Target Site : Tokai R&D Center of JAEA

Calculation Conditions and Input Data for OSCAAR

- CFF and source term data are taken from level 2 seismic PRA[1]

- CFFs are the products of the conditional CFFs and the seismic probability of Ibaraki prefecture[2] where Tokai R&D Center is located.

1 JNES. Methodology of level 2 PSA (BWR)", JNES/SAE06-046. Tokyo; 2006.
2 The Headquarter for Earthquake Research Promotion, Long-term assessment of the seismic activity from Sanriku to Boso. Tokyo; 2009.

Calculation Conditions and Input Data for OSCAAR

CFF and source term data of each severe accident sequence

Accident sequence[1]	Release sequence number	CFF [year^{-1}]	Release time [hr]	Release duration [hr]	Release ratio [-]
					Noble gas
					1
TB	1	2.75E-05	12.7	4.0	2.9E-01
	2		16.7	25.0	7.1E-01
TW	1	2.61E-05	12.3	4.0	3.3E-02
	2		16.3	12.7	6.3E-01
	3		29.0	29.3	3.4E-01
TBU	1	7.37E-06	1.0	7.3	5.4E-06
	2		8.3	6.7	1.7E-01
	3		15.0	26.7	3.4E-01

…

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JNES. Methodology of level 2 PSA (BWR)", JNES/SAE06-046. Tokyo; 2006.

Calculation Conditions and Input Data for OSCAAR

- 248 Meteorological sequences were selected by bin sampling method to represent 8760 meteorological data[1].

1 T. Homma, J. Ishikawa, K. Tomita, K. Muramatsu. Radiological Consequence Assessments of Degraded Core Accident Scenarios Derived from a Generic Level 2 PSA of a BWR, JAERI-Research 2000-060; 2000.

Calculation Conditions and Input Data for OSCAAR

Radiation protection scenario

Counter-measure	Area and dose level	Time of starting the countermeasure	Period
Sheltering	Within 50 km and over 10 mSv/week	1 hour after the release starts	24 hours
Evacuation	Within 30 km and over 50 mSv/week	After the release starts	7 days
Relocation	Starting: over 20 mSv/year Returning: under 20 mSv/year	After finishing the evacuation	Returning home after the dose level reaches 20 mSv/year

1 IAEA. Intervention Criteria in a Nuclear or Radiation Emergency”, Safety Series No.109; 1994.
2 ICRP. The 2007 Recommendations of the International Commission on Radiological Protection, Pub. 103; 2007.
3 T. Homma, J. Ishikawa, K. Tomita, K. Muramatsu. Radiological Consequence Assessments of Degraded Core Accident Scenarios Derived from a Generic Level 2 PSA of a BWR, JAERI-Research 2000-060; 2000.

Estimation of Cost per Severe Accident

- Input data from OSCAAR
  - Sheltered, evacuated, relocated populations and periods
  - Collective dose

- Radiation effect cost
  - Willingness to pay (WTP)
- Psychological effect cost
  - Compensations of Fukushima Accident
- Sheltering, evacuation and relocation costs
  - Income losses, transportation costs, accommodation costs, capital utility losses
- Food intake restriction cost
  - losses of products and waste management
- Alternative source cost
  - Replace NPP by Fossil fuel PP
- Harmful rumor cost
  - Information from Fukushima Accident
- Decontamination cost
  - Decontamination work and waste management
- Decommissioning cost
  - Information from TMI and Chernobyl accidents

Normalized Cost per Severe Accident

Silva K, Ishiwatari Y, Takahara S. Cost per severe accident as an index for severe accident consequence assessment and its applications. Reliab. Eng. Syst. Saf. 2014;123:110-22.

Breakdowns of Cost per Severe Accident

Silva K, Ishiwatari Y, Takahara S. Cost per severe accident as an index for severe accident consequence assessment and its applications. Reliab. Eng. Syst. Saf. 2014;123:110-22.

Conclusions

- *Cost per severe accident of a virtual 1,100 MWe BWR-5 was estimated.*
  - *Cost per severe accident can cover large scope of severe accident consequences, including radiation effects, economic, social and environmental impacts.*
  - *The results emphasize the importance of careful consideration of low probability accident sequences since they may have large consequence.*
  - *Decontamination cost, relocation cost and radiation effect cost are the three important cost components of the cost per severe accident.*

Major Shortcoming of the Cost per Severe Accident Estimation Scheme

Decontamination cost

Large contribution but:

- Inadequate data collection for values of parameters
- Some assumptions are applied without enough consideration

Silva K, Ishiwatari Y, Takahara S. Cost per severe accident as an index for severe accident consequence assessment and its applications. Reliab. Eng. Syst. Saf. 2014;123:110-22.

Objectives

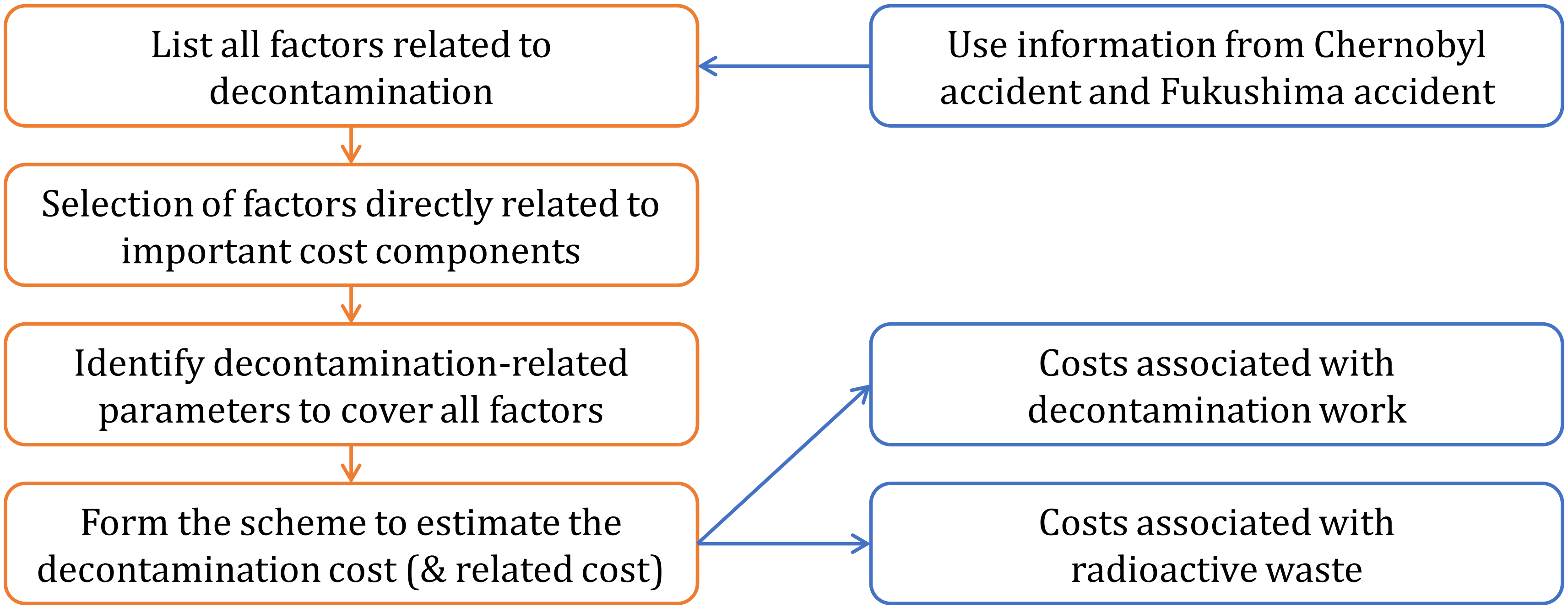
"To formulate the decontamination model for the calculation of cost per severe accident."

"To perform a sensitivity analysis to identify:

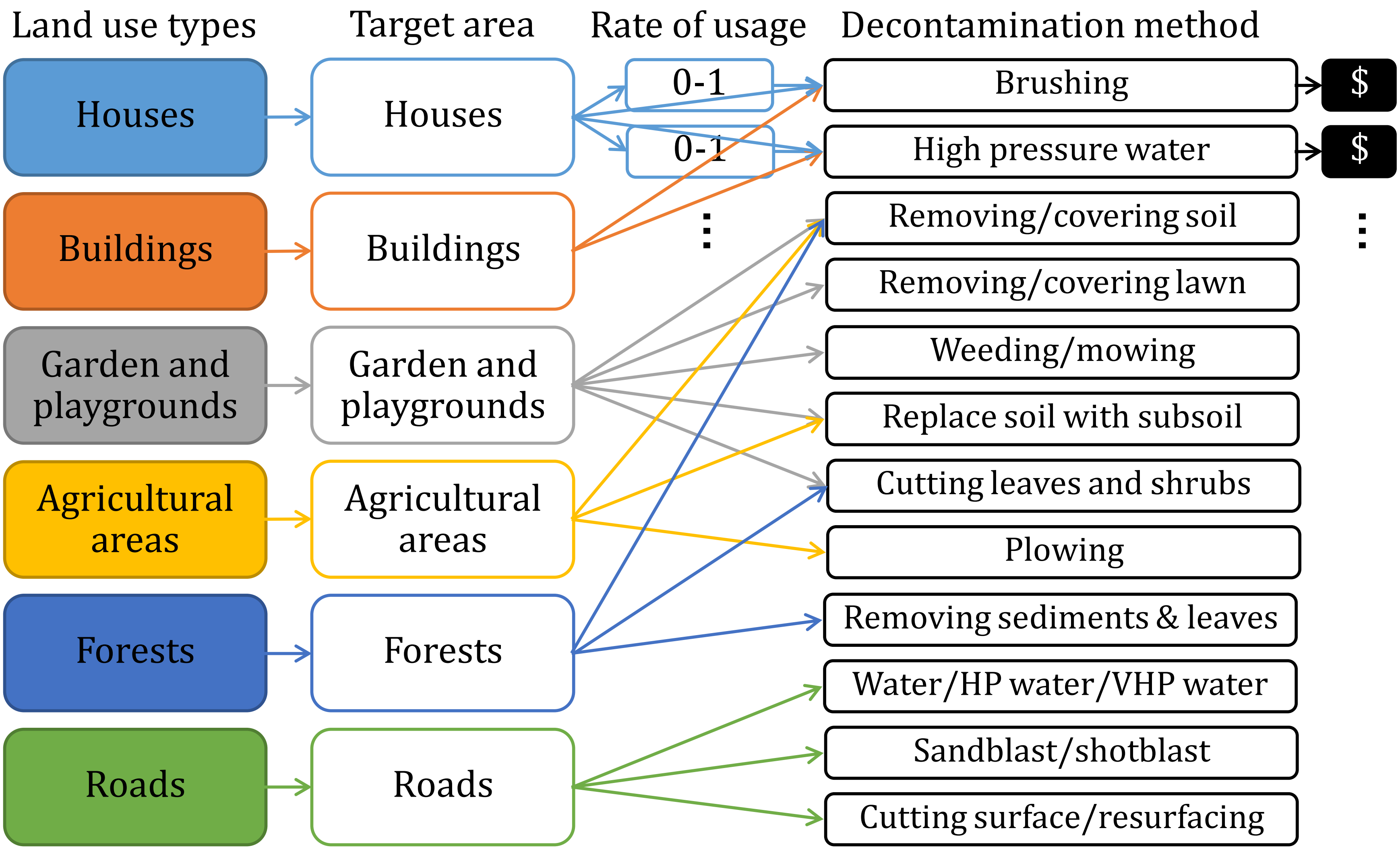
- *Parameters with large influence on accident cost calculation and large extent of interactions with other parameters;*
- *Parameters with negligible influence;*

in order to obtain a simplified model"

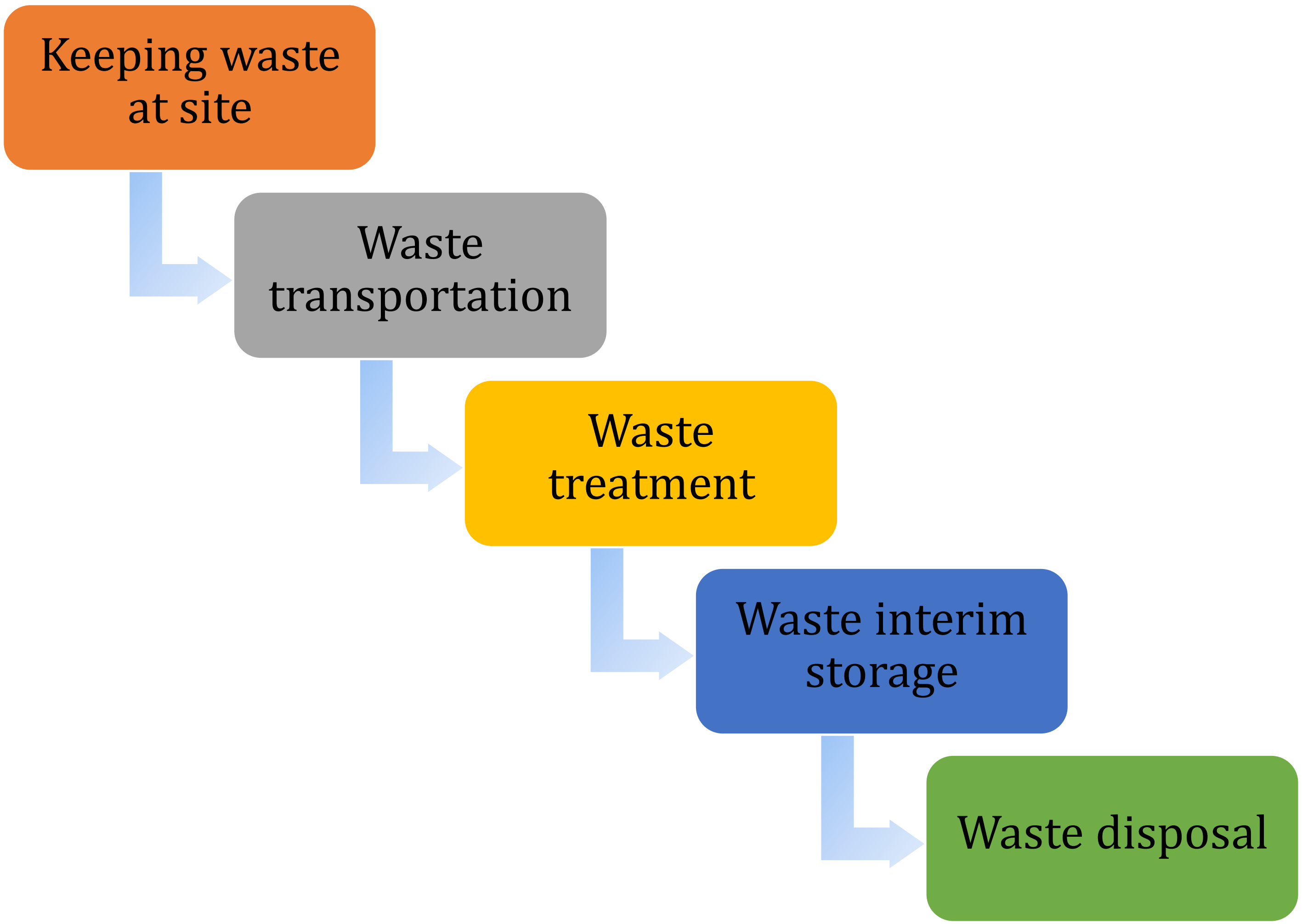
Formation of Decontamination Model



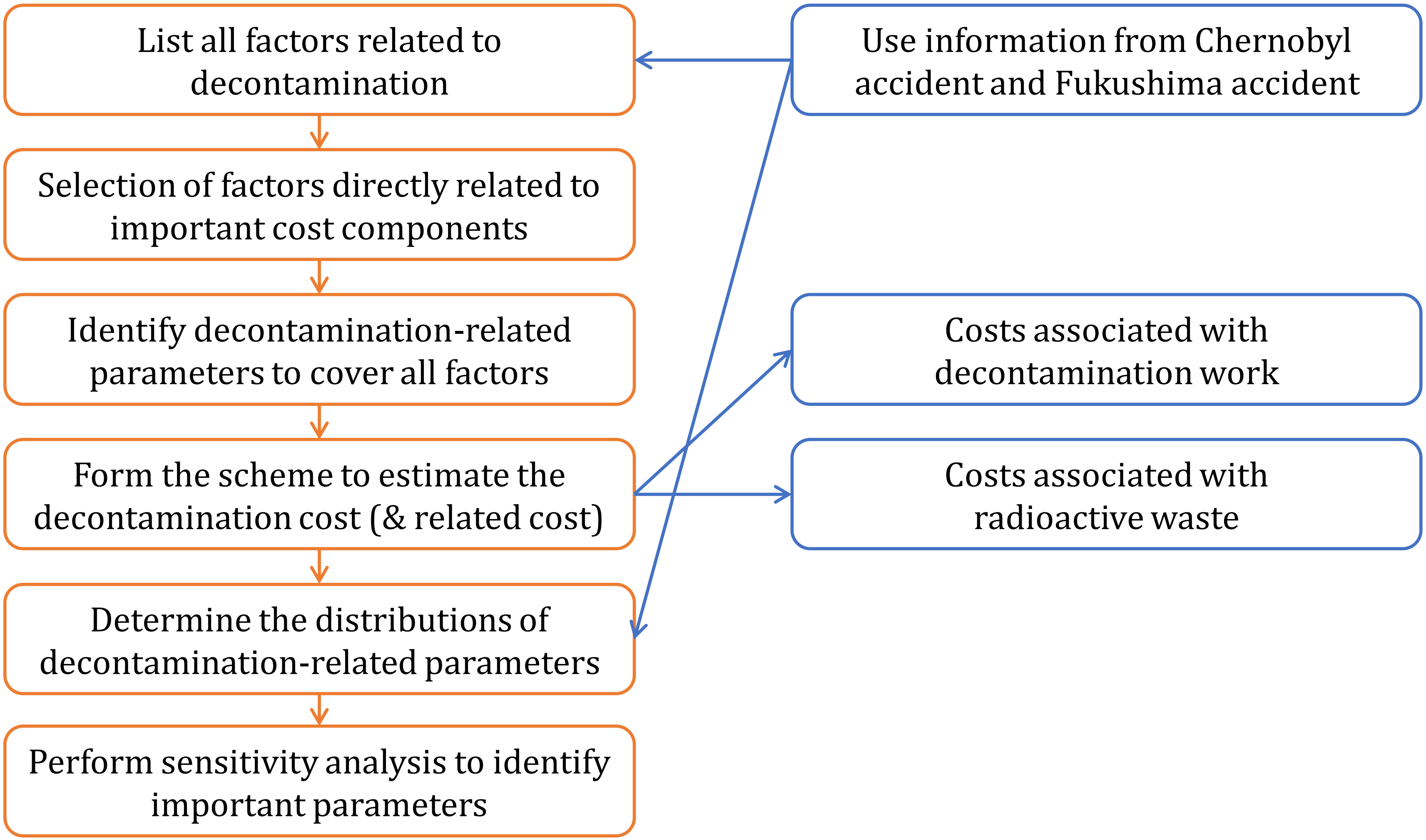
Costs Associated with Decontamination Work



Costs Associated with Radioactive Wastes



Formation of Decontamination Model



Sensitivity analysis: Elementary effect method

Why elementary effect method (Morris method)?

- The method is simple.
- It is somewhere between local sensitivity analysis and global sensitivity analysis.
- The results are simple: only μ^*s and σs.
  - μ^*s help identify parameters with large contribution to cost per severe accident
  - σs help identify parameters having large interactions with others

$$\boxed{\mu^* = \sum_{i=1}^{r} \left|d_i\right| / r}$$

$$\boxed{\sigma = \sqrt{\sum_{i=1}^{r} \left(d_i - \mu\right)^2 / r}}$$

μ^*s and σs of all parameters

- 1: Dose for decontamination target area setting
- 53, 55, 56, 58: Waste management related parameters
- 60: Number of workers involved in decontamination
- 36, 38, 44: Volumes of waste generated per unit area
- 11, 16: Rates of usage of decontamination techniques
- 19: Selection of the way to distribute the unit costs

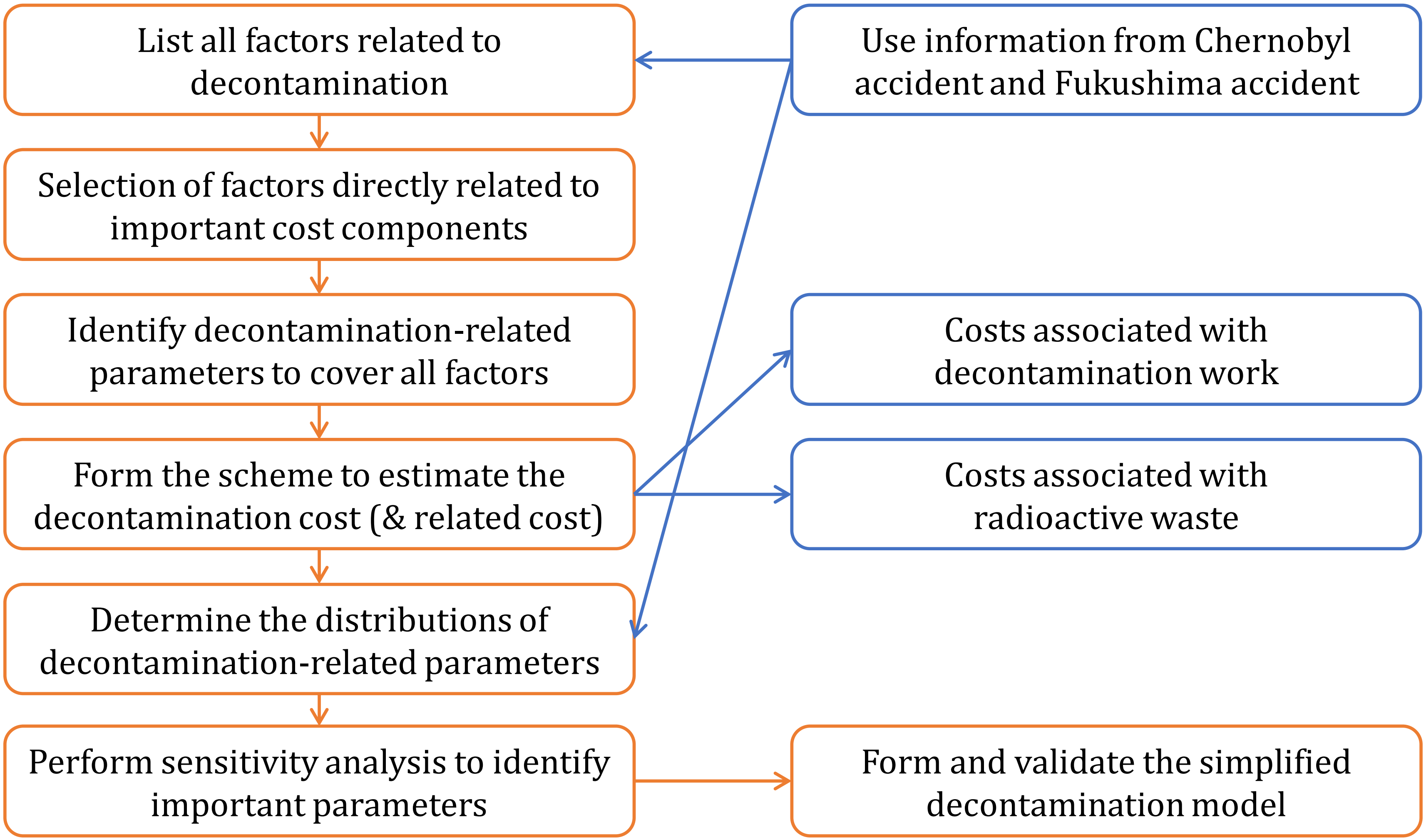
K. Silva, K. Okamoto, Y. Ishiwatari, S. Takahara, J. Promping. Development of Accident Consequence Assessment Scheme using Accident Cost and Consideration of Decontamination Model. PSAM12. Hawaii; 2014.

μ^*s and σs of all parameters (zoomed-up version)

- μ^*s and σs over 0.05
  - Rates of usage of some decontamination techniques
  - Unit costs of some decontamination techniques
  - Other waste management-related parameters
  - Work speeds of some decontamination techniques
- None of parameters that affect radiation effect cost are influential
  $\Rightarrow$ Small interaction between decontamination cost and radiation effect cost

K. Silva, K. Okamoto, Y. Ishiwatari, S. Takahara, J. Promping. Development of Accident Consequence Assessment Scheme using Accident Cost and Consideration of Decontamination Model. PSAM12. Hawaii; 2014.

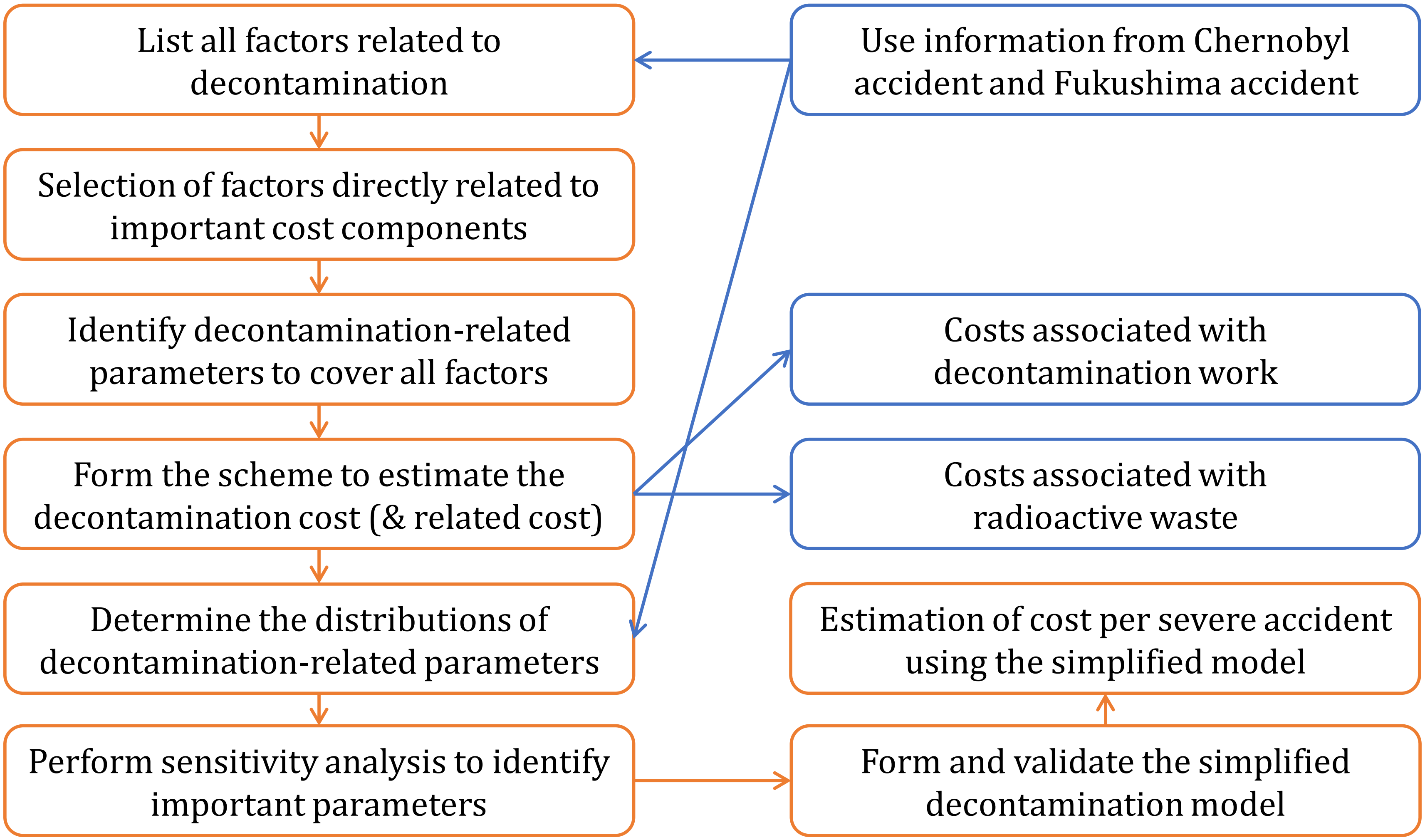
Formation of Decontamination Model



Validation of the simplified model

K. Silva, K. Okamoto, Y. Ishiwatari, J. Promping. Formation of Decontamination Cost Calculation Model for Severe Accident Consequence Assessment. NUTHOS10. Okinawa; 2014 (To be presented).

Formation of Decontamination Model



Estimation of the Cost per Severe Accident and Comparison with the Old Model

K. Silva, K. Okamoto, Y. Ishiwatari, J. Promping. Formation of Decontamination Cost Calculation Model for Severe Accident Consequence Assessment. NUTHOS10. Okinawa; 2014 (To be presented).

Conclusions [1/2]

- *The decontamination model was reconsidered.*
- *A sensitivity analysis was performed.*
- *Parameters that are influential to the cost per severe accident are:*
  - *the dose of setting decontamination target area;*
  - *a set of waste management-related parameters;*
  - *the number of workers involved in decontamination work* *etc.*
- *None of parameters that affect radiation effect cost are influential.*
  - *Small interaction between decontamination cost and radiation effect cost.*

Conclusions [2/2]

- *A simplified decontamination cost calculation model is formed based on the results of the sensitivity analysis, and validated by comparing with the full model.*
- *The simplified model was finally used to perform cost per severe accident calculation and compared with the previous study.*
  - *Decontamination cost increased its importance significantly;*
  - *Cost per severe accident increased by 2.15 times.*
  - *The results indicate that it is necessary to carefully consider the decontamination scheme, including the waste management.*

Future Work:
Thai Consequence Assessment Code

- TINT is now planning to build a Thai consequence assessment code based on the knowledge gained from the research with JAEA and UT using OSCAAR.
  - This maybe used by the regulatory body (OAP) or the future nuclear power plant utility (EGAT or Ministry of Energy).
- We are learning the way to incorporate the weather and geological information into the dispersion model.
  - We are also thinking about the possibility of integration with GIS (Geographic Information System).

Summary

- *We proposed "cost per severe accident" as an index to help enlarge the scope of consequence assessment, in order to take into account all anticipated consequences.*
  - *The index was formed based on lessons learned from the Fukushima Accident.*
- *The decontamination model was newly formed to replace the old model of which the data was inadequate and the assumptions were not realistic.*
- *TINT has a plan to build its own consequence assessment code*

References

K. Silva, Y. Ishiwatari, S. Takahara. Cost per Severe Accident as an Index for Severe Accident Consequence Assessment and its applications. Reliab. Eng. Syst. Saf. 2014;123:110-22.

K. Silva, Y. Ishiwatari, S. Takahara. Integration of Direct/Indirect Influences of Severe Accident for Improvement of Nuclear Safety. ICONE20. California; 2012.

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K. Silva, K. Okamoto, Y. Ishiwatari, S. Takahara, J. Promping. Development of Accident Consequence Assessment Scheme using Accident Cost and Consideration of Decontamination Model. PSAM12. Hawaii; 2014.

K. Silva, K. Okamoto, Y. Ishiwatari, J. Promping. Formation of Decontamination Cost Calculation Model for Severe Accident Consequence Assessment. NUTHOS10. Okinawa; 2014 (To be presented).