Level 3 PSA in the KHNP SOARCA
- Plan and Expected Outcomes -

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3. **Summary**

Introduction

Project Overview

- **Project Title**

  Development of the Level 2&3 PSA Technologies based on the State-of-the Art Technology

- **Objective**
  - Fulfillment of newly established safety goals (June 2015) and recent amendment of the PSA legislation
  - Build-up of base technologies for realistic accident progression and off-site consequence analysis based on the latest technologies and computational tools (such as MELCOR 2.1 and WinMACCS)
  - Establishment of Korea-specific risk assessment and management system

- **Pilot-Plants**
  - Shinkori units 3&4 (APR1400 series)
  - Wolsung unit 1 (CANDU Type)

- Principal Investigating Organization (Contractor): **KHNP**
- Collaboration: **KAERI** (Subcontractors : **FNC** & **ACT**), **SNL** (US)
- Project Period: 2016.07 ~ 2019.06 (36 Months)

KHNP SOARCA Project

Objectives

Development of **optimal evaluation technique of severe accident and off-site consequence** based on the state-of-the-art technology and analysis tools

Step 1. Level 2&3 PSA : The Latest Technology Benchmarking and Development of Base Technology

- Benchmarking of the latest analysis technology (with SNL) and establishment of counterplan to resolve regulation issues
- Development of Level 2 PSA model for optimal analysis (Accident progression, Severe accident mitigation and SAMG reflection etc.)
- Modeling of MELCOR/MAAP5/ISAAC Inputs for optimal analysis of accident progression and radioactive source-term behaviors
- Development of Level 3 PSA code (WinMACCS) input models (Site-specific, Food intake, evaluation of loss cost etc.)

Step 2. Level 2&3 PSA : Optimum Analysis of Pilot-Plants

- Optimization of Level 2&3 PSA model and Severe accident code(MELCOR/MAAP5/ISAAC) input model
- Optimization of Level 3 PSA code input model (WinMACCS) : Input of radiation reaction model and effect of resident reaction analysis etc.
- Optimization of off-site consequence analysis (Population Dose, Early/Cancer Fatality Risk, CCDF etc.)
- V&V of severe accident (MELCOR/MAAP5/ISAAC) and off-site consequence analysis code (WinMACCS) input modelis (with SNL, FAI)

Step 3. Effective Management of SA Mitigation Systems and Regulation-responding Technology

- Reflection of review result of severe accident and off-site consequence analysis codes
- Development of Off-site risk standardization (evaluation of mitigating system of severe accident, dealing with regulatory issue)
- Reliability evaluation of severe accident mitigation systems and suggestion of operation improvements
- Dealing with regulatory issue and requirement fulfillment (PSA legislation and Wolsung#1 ST improvement plan fulfillment)

Evolution of Relevant Technology

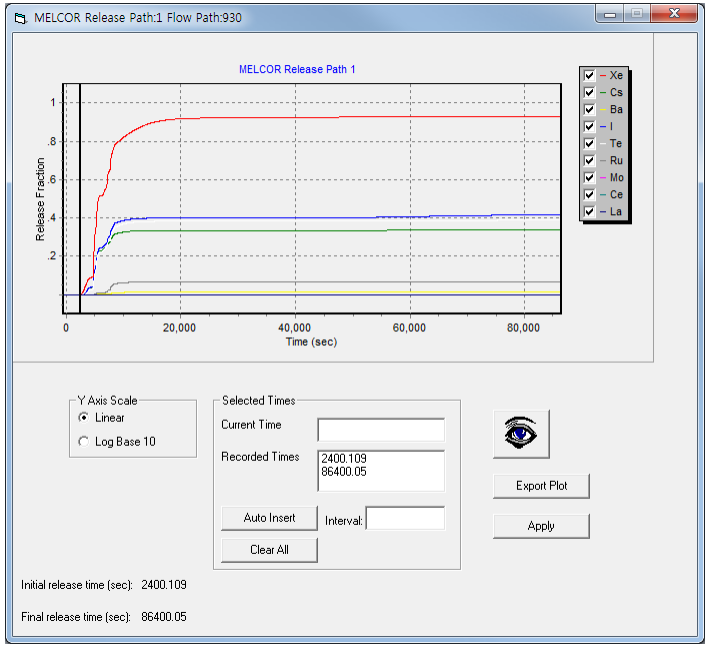
- Level 3 PSA in the US
  - **Reactor Safety Study** (WASH-1400, 1975): The first implementation of the Level 3 PSA
  - **Technical Guidance for Siting Criteria Development** (NUREG/CR-2239, 1982)
    - Development of technical guidance to select reactor build site
    - Assessment of early and late fatalities
  - **Estimates of the Financial Consequences** of Nuclear Power Reactor Accidents (NUREG/CR-2723, 1982)
  - **Seabrook Station Probabilistic Safety Assessment** (PLG-0300, 1983)
    - Multi-Unit PSA
  - **Severe Accident Risk** (NUREG-1150, 1990) => WASH-1400 Re-baseline Study
  - **Study of protective action recommendation (PAR)** (NUREG/CR-6953, Vol. 1, 2007)
  - **State-of-the-Art Reactor Consequence Analyses (SOARCA)** (NUREG-1935, 2013) (NUREG/CR-7110 Vol. 1&2, 2013) => NUREG/CR-2239 Re-baseline Study
  - SOARCA Uncertainty Analysis
  - Analysis of Filtered Containment Vent
  - Full-Scope & Comprehensive Site Level 3 PRA (SECY-11-0089) - Vogtle Units 1&2

Plan and Expected Outcomes

- In the View Point of MACCS Modeling -

Source Term / Interfacing Level 2 & 3 PSA

- Level 2 PSA Tool
  - **MAAP**: Typically used tool in Korea
  - KHNP SOARCA project
    - **MELCOR 2.1** / **MAAP 5.03** (**APR1400**)
    - **ISSAC 4.03** (**CANDU**)
- Interfacing L2-L3 PSA
  - MELCOR output - (MELMACCS) - MACCS input
    MAAP output - (conversion tool) - MACCS input
    - Making the best use of Level 2 PSA results
      - L2 PSA results: plant-specific source term calculation by using MELCOR and MAAP
    - Time-discretization of plume release
      - Enable semi-dynamic modeling of source release
    - Application of particle size distribution (MELMACCS only)
      - Dry deposition



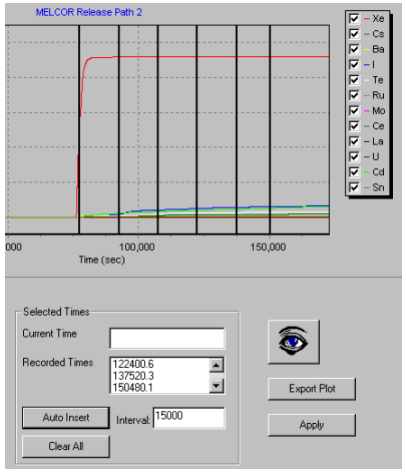


*Image from MELMACCS Version 1.7.0 User's Guide

Atmospheric Dispersion and Deposition

- Dispersion Model
  - Gaussian plume model
  - Dispersion parameter
    - Lookup table for practical assessment
    - Power-law function for sensitivity analysis
- Plume Rise
  - Difficult to convert MAAP results into plume rise model of MACCS
  - More realistic plume rise model by using MELCOR results
- Building Wake
  - Applying design of APR1400 and CANDU
    - $\sigma_{y_0} = 0.23\ W_b$ and $\sigma_{z_0} = 0.47\ H_b$
- Deposition
  - Dry deposition: Dependent on surface roughness
  - Wet deposition: Site independent

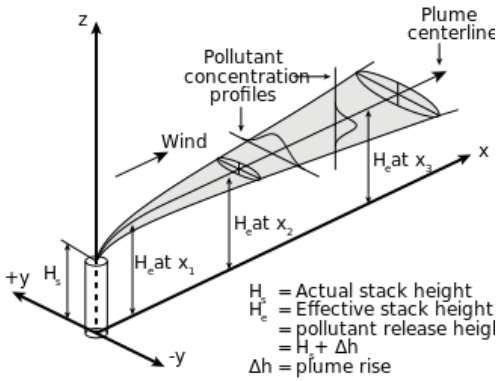


*Image from https://en.wikipedia.org/wiki/Outline_of_air_pollution_dispersion

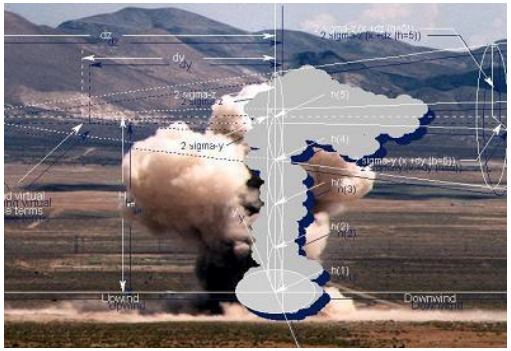


*Image from HotSpot code homepage: https://narac.llnl.gov/hotspot

$$\ln(v_d) = a + b(\ln(d_p)) + c(\ln(d_p))^2 + d(\ln(d_p))^3 + e(z_0) + f(z_0)^2 + g(v)$$

where

v_d = deposition velocity (cm/s)

d_p = hydrodynamic particle diameter (μ) with limits

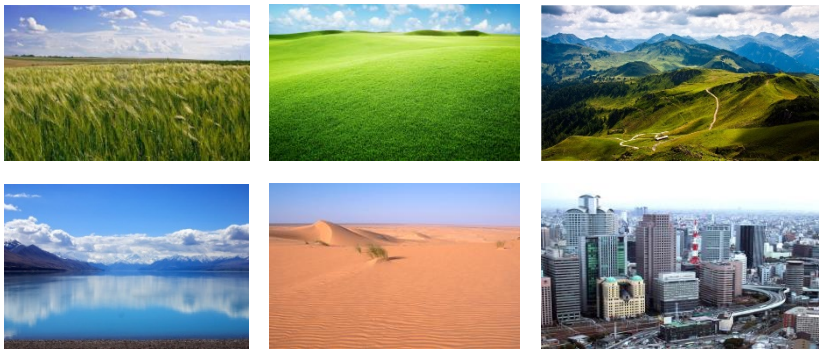
z_0 = surface roughness (m) with limits

v = wind speed (m/s) with limits

Surface Roughness

- Highly Influencing Factor on
  - Atmospheric dispersion (ZSCALE)

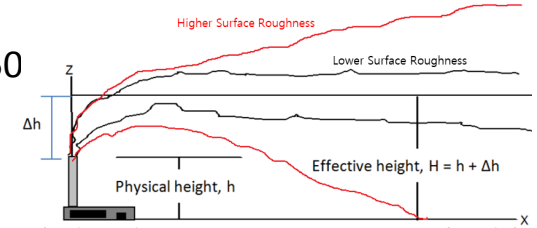
$$\sigma_z = \sigma_{z,\,PG}\left(\frac{z_0}{3}\right)^{0.2}$$



  - Dry deposition

$$\ln(v_d) = a + b(\ln(d_p)) + c(\ln(d_p))^2 + d(\ln(d_p))^3 + e(z_0) + f(z_0)^2 + g(v)$$

  - **Sensitivity analyses** on the effect of the **surface roughness** parameter in the US SOARCA project
    - z_0 = 10 cm → 60 cm
      - 20% LCF risk reduction for the intermediate distances (10 to 50
      - 10% LCF risk increase within 10 miles

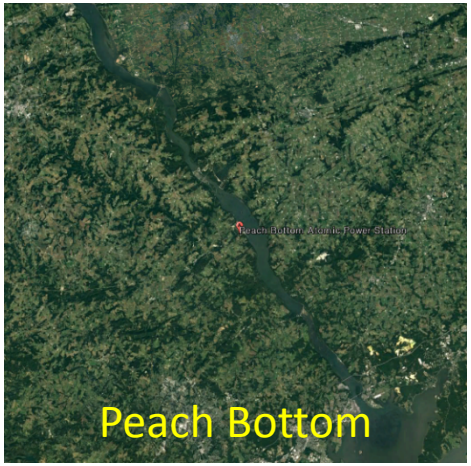


*Background image source: HotSpot Version 3.0 User's Guide (2014)

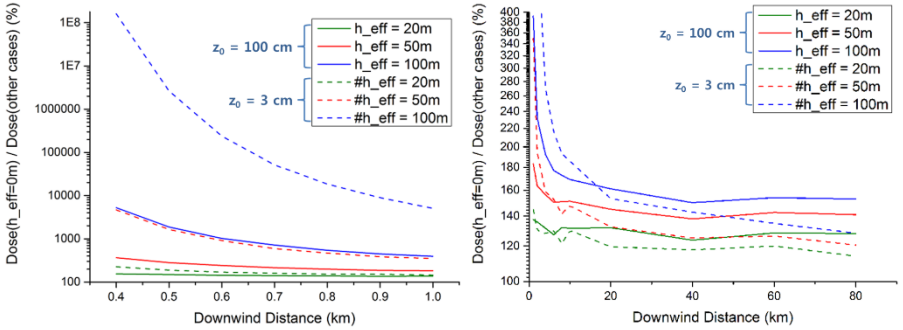
- Characterized by Only One (point) Value
  - MACCS cannot handle multiple grid information of surface roughness.

Surface Roughness (cont.)

- How can we calculate representative surface roughness parameter for complex terrain?



- Higher surface roughness for complex terrain
  - Realistic for intermediate distances
  - Conservative for the area adjacent to a plant

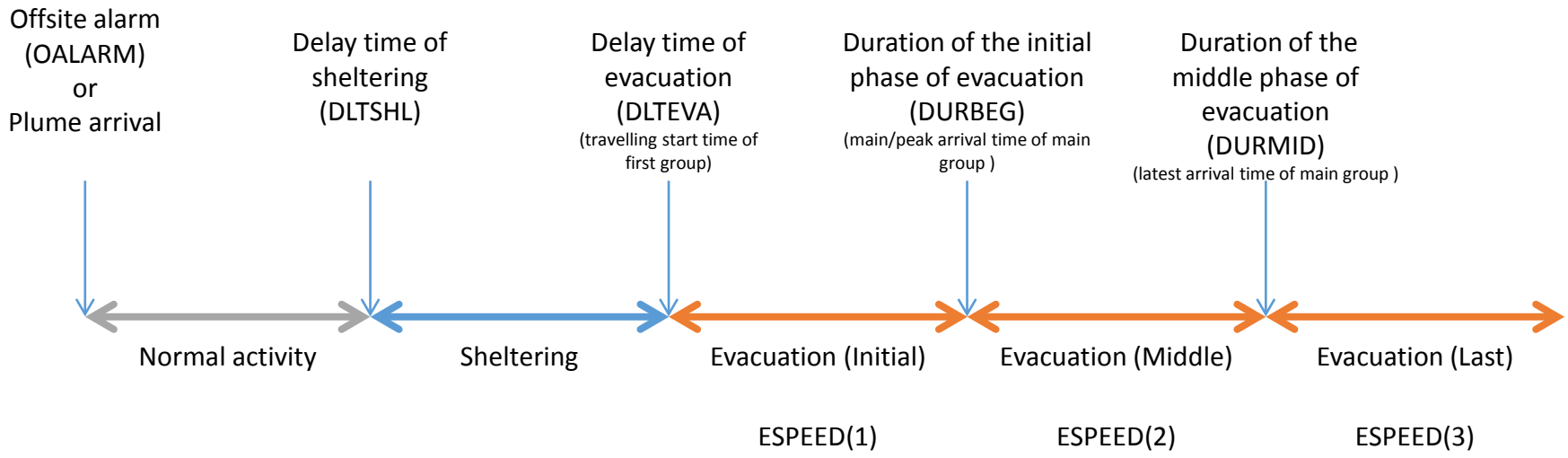


*Reference:
"Examination of Conservatism in Ground-level Source Release Assumption when Performing Consequence Analysis," Sung-yeop Kim and Ho-Gon Lim, Transactions of the KNS Autumn Meeting, 2015

*Image source: google earth

Emergency Response

- Evacuation Time Estimate (ETE)



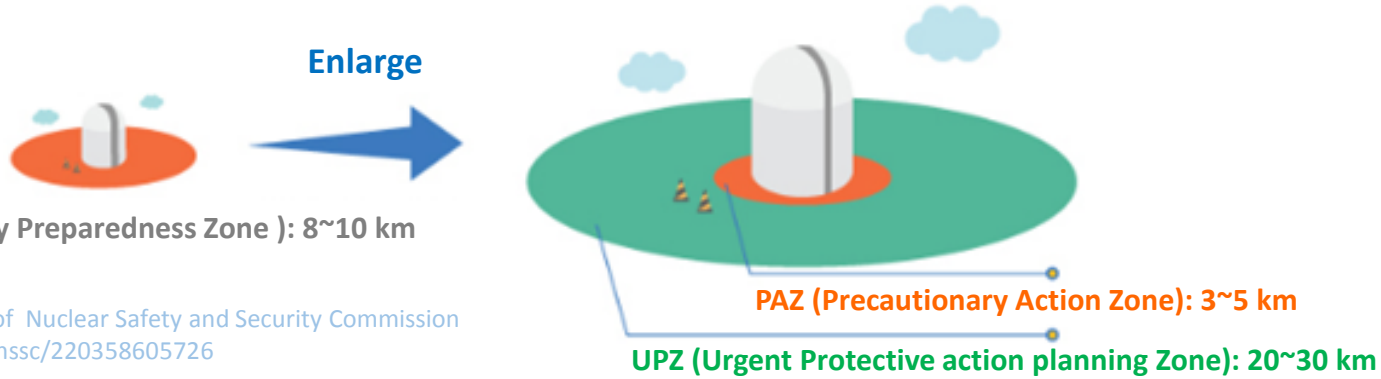
- % population: Evacuate following above scenario
- % population: Do not follow evacuation instruction

*References:

- Y. G. CHUNG, G. B. LEE, S. Y. BANG, S. M. KIM, and E. M. LEE, "Public Evacuation Time Estimates within EPZ of Ulchin Site," J. of the Korean Radioactive Waste Society, 3, 4, 359 (2005).
- U.S.NRC. NUREG/CR-6864, *Identification and Analysis of Factors Affecting Emergency Evacuations*, Washington D.C.: NRC, January 2005.

Emergency Response (cont.)

- Revision of Emergency Preparedness Zone in Korea (May 2015)



*Reference: Official Blog of Nuclear Safety and Security Commission
http://blog.naver.com/prnssc/220358605726

- EPZ of Each Country

Country	Range		Country	Range	
	PAZ	UPZ		PAZ	UPZ
IAEA Recommendation	3~5 km	5~30 km	Swiss	3~5 km	20 km
Korea	3~5 km	20~30 km	Rumania	3 km	10 km
Japan	5 km	30 km	Belgium	– Preparation of Sheltering and Evacuation: 10 km – Preparation of KI Distribution: 20 km	
USA	3.2~8 km	16 km	Netherlands	– Preparation of Evacuation: 5 km – Preparation of KI Distribution: 10 km – Preparation of Sheltering: 20 km	
China	3~5 km	7~10 km	Germany	2km	– Preparation of Sheltering and Evacuation: 10 km – Preparation of KI Distribution: 25 km
Hungary	3 km	30 km			

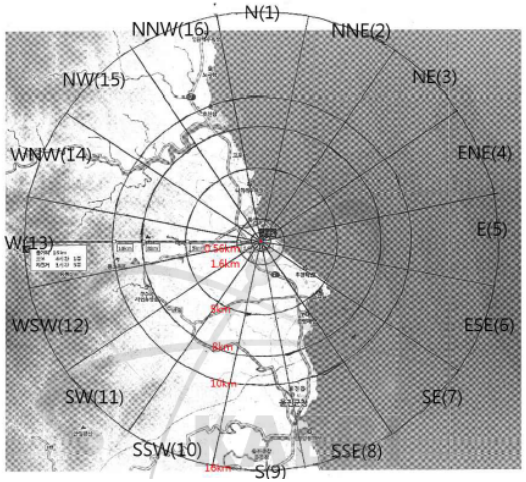
*Reference: Official Blog of Nuclear Safety and Security Commission http://blog.naver.com/prnssc/220359390887

Emergency Response (cont.)

- PAZ and UPZ for Kori and Wolsung site

*Reference: Official Blog of Nuclear Safety and Security Commission http://blog.naver.com/prnssc/220830414319

- Applicability of Network Evacuation Model



*Example for the reference site: *Development of a foundation technology for Risk-informed emergency preparedness optimization*, KAERI/CM-2414/2016

Emergency Response (cont.)

- Criteria of Emergency Protective Action in Korea

Protective Action	Decision Criteria
Sheltering (not exceeding 2 days)	10 mSv
Evacuation (not exceeding 1 week)	50 mSv
Distribution of KI	100 mGy
Dose dependent relocation	30 mSv / first 1 month 10 mSv / next 1 month
Condemnation	1 Sv / lifetime (70 years)

*Image from: https://hubpages.com/education/Japan-2011-The-tsunami-that-caused-a-nuclear-meltdown

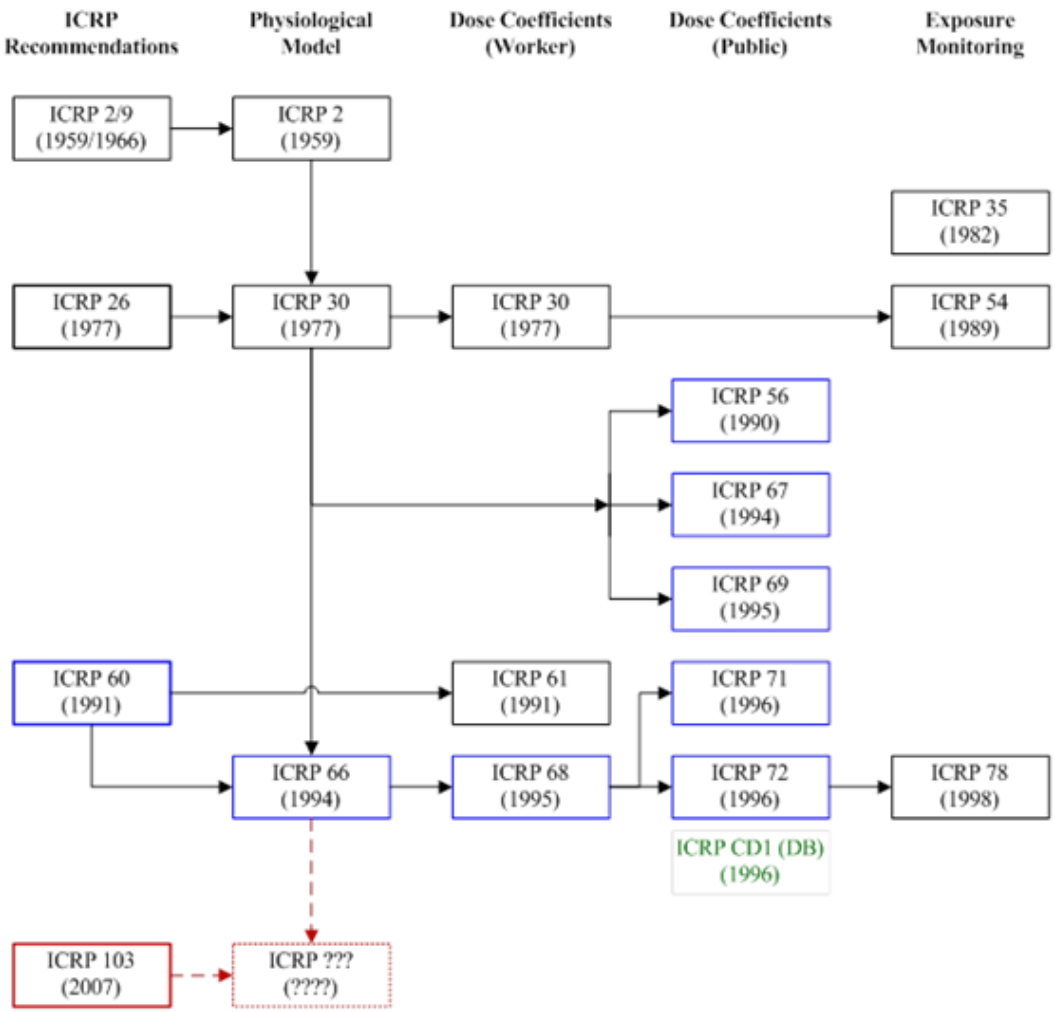
- Cohort Modeling
  - Applying site-specific population distribution and type of evacuation

*Image from: http://www.fukushimawatch.com/2015-12-23-only-16-percent-of-fukushima-residents-had-received-evacuation-notices-by-a-day-after-the-catastrophe-according-to-new-study.html

- Shielding and Protection Factors
  - Applying domestic characteristics of construction and public lifestyle

Dose Coefficient (cont.)

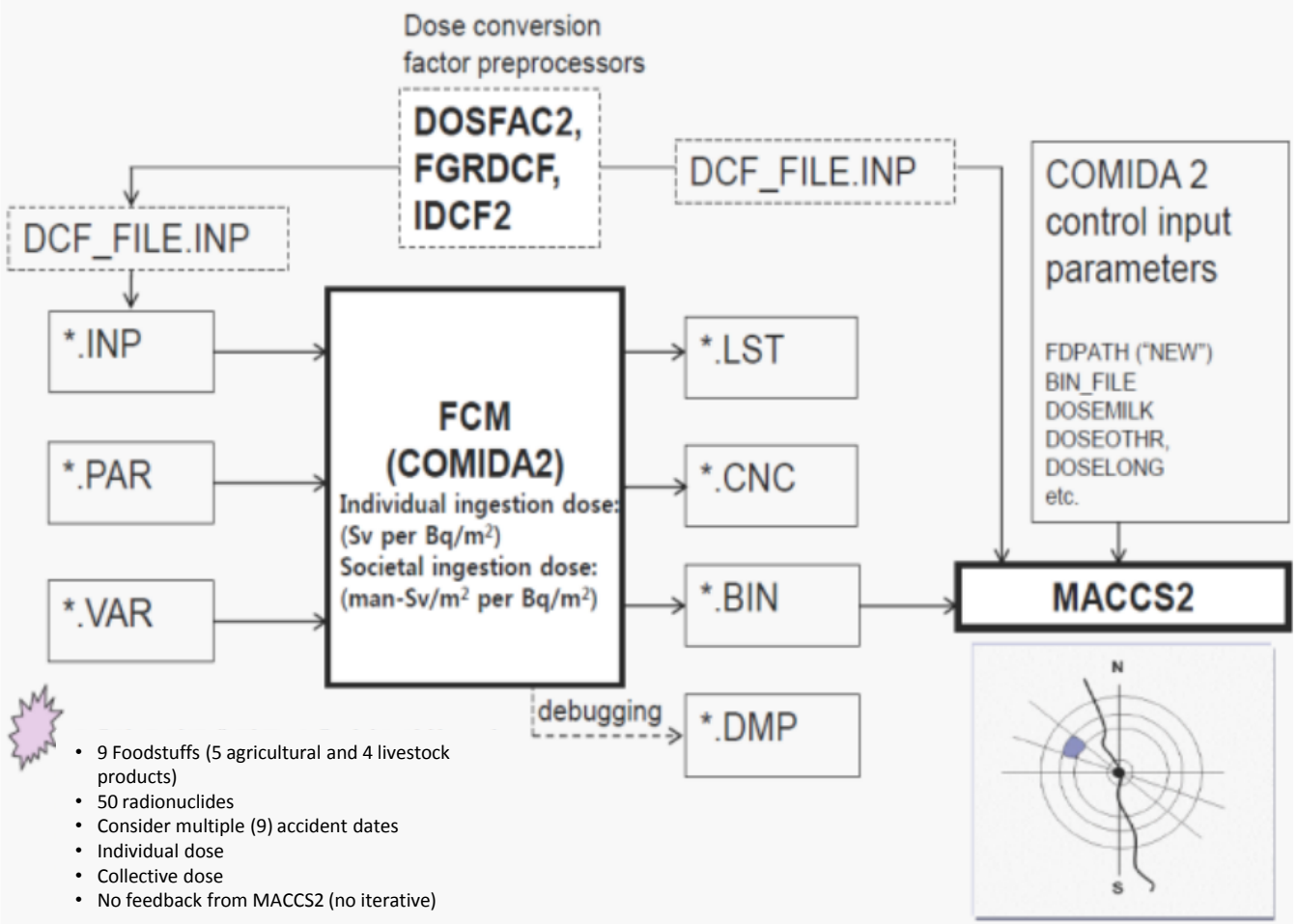
- ICRP Dose Coefficient



*Reference: A Study on the Framework for Radiation Dose Estimation in Level 3 PSA, KAERI/TR-5568/2014

Long-Term Ingestion Dose

- Food Chain Model (FCM)

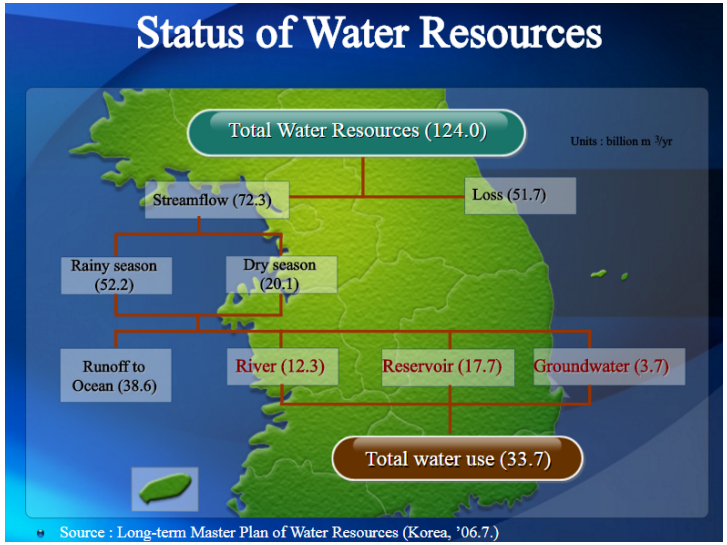


- 9 Foodstuffs (5 agricultural and 4 livestock products)
- 50 radionuclides
- Consider multiple (9) accident dates
- Individual dose
- Collective dose
- No feedback from MACCS2 (no iterative)

*Reference:
"A Development of Domestic Food Chain Model Data for Chronic Effect Estimation of Off-site Consequence Analysis," Seok-Jung HAN, Dong-Kwon KEUM, Seung-Cheol JANG, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 7-8, 2015

Long-Term Ingestion Dose (cont.)

- FCM Data Development
  - ECOREA FCM Code for the annual ODCM (Offsite Does Calculation Manual) activities for operating plants from 1990's to current
    - Collecting Korean and site-specific food data
  - Porting ECOREA FCM data to COMIDA2 for Level 3 PSA



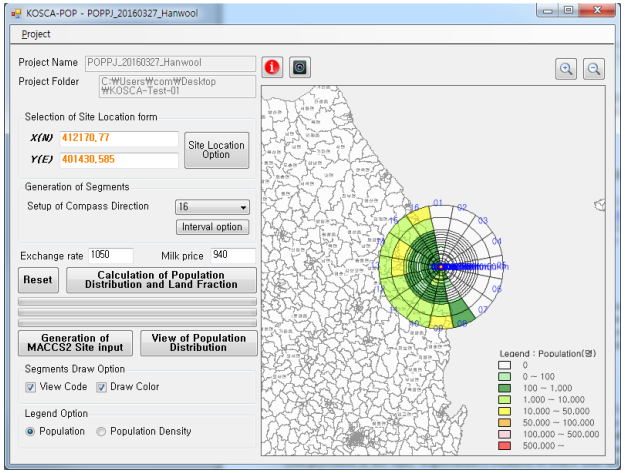
- Water Ingestion Data Development
  - Water drink ratio: 5% of total water resource
  - Large area of rice farming filled with water

→ Relatively higher radiation exposure from a contaminated land

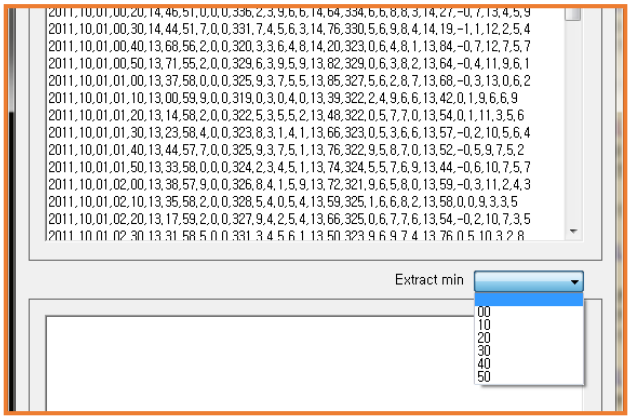
SITE and MET Input:

Shinkori and Wolsung site

- Population and Land Fraction Data
  - 2010 census data
  - Recent digital geographic map



- Meteorological Data
  - V&V of measured meteorological data by checklist extracted from reference standards:
    - ASME/ANS RA-S-1.4-2013 : Probabilistic Risk Assessment Standard (Technical Requirements for Meteorological Data)
    - US NRC Reg. Guide 1.23(Meteorological Monitoring Programs for Nuclear Power Plants)
    - ANSI/ANS-3.11-2015(Determining Meteorological Information at Nuclear Facilities)



Summary

- **Interfacing Level 2 & 3 PSA**
  - Level 2 PSA Tool: **MELCOR 2.1** / **MAAP 5.03** (**APR1400**) and **ISSAC 4.03** (**CANDU**)
  - Level 3 PSA Tool: **WinMACCS**
- Atmospheric Dispersion
  - Gaussian plume model
    - Dispersion parameters: **Lookup table** for **practical assessment** / **Power-law function** for **sensitivity analysis**
    - Application of state-of-the-art technology and plant-specific data for plume rise and building wake
- **Surface Roughness**
  - Highly influencing factor on **atmospheric dispersion** and **dry deposition**
  - Effort to establish **site-representative value** and **sensitivity analysis**
- Emergency Response
  - Recent change in definition of Emergency Planning Zone (**PAZ**, **UPZ**)
  - Task
    - **ETE** for new EPZ
    - **Network evacuation** model
    - **Cohort** modeling
    - Application of **criteria** **for emergency protective action** of Korea
- Dose and Health Effect
  - **Applicability** of ICRP 26 based and ICRP 60 based DCFs and **appropriate** health effect model
- Site and Meteorological Data
  - Application of recent statistical / measured data and its verification

Thank you for your attention.