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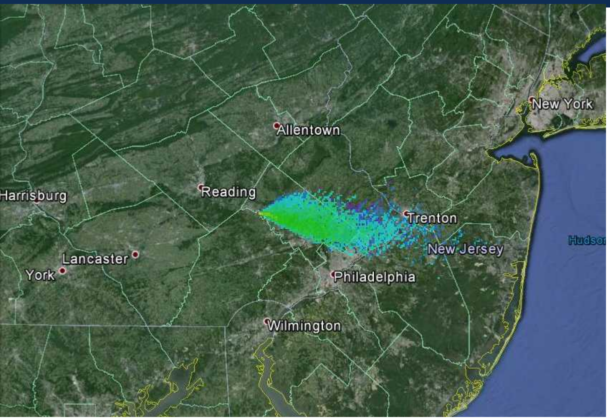

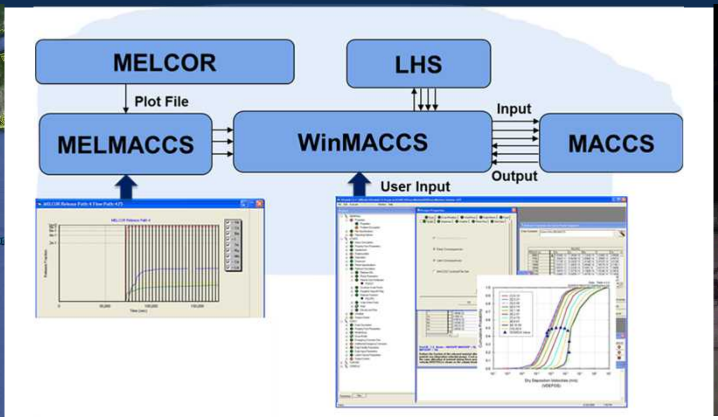

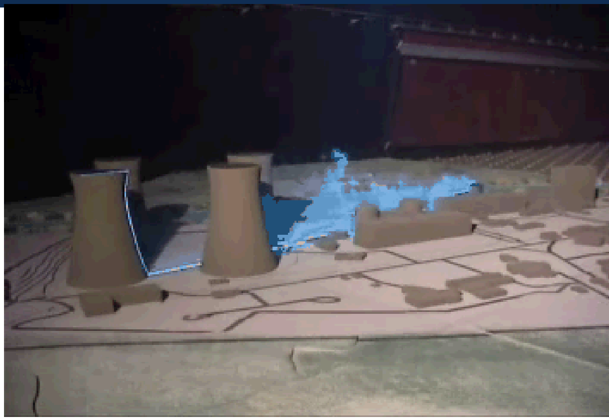

Atmospheric Transport and Dose Calculations: Concepts and Implementation in the MACCS Code

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Presented at the Simulation Technologies Technical Exchange Workshop, Sandia National Labs, July 16, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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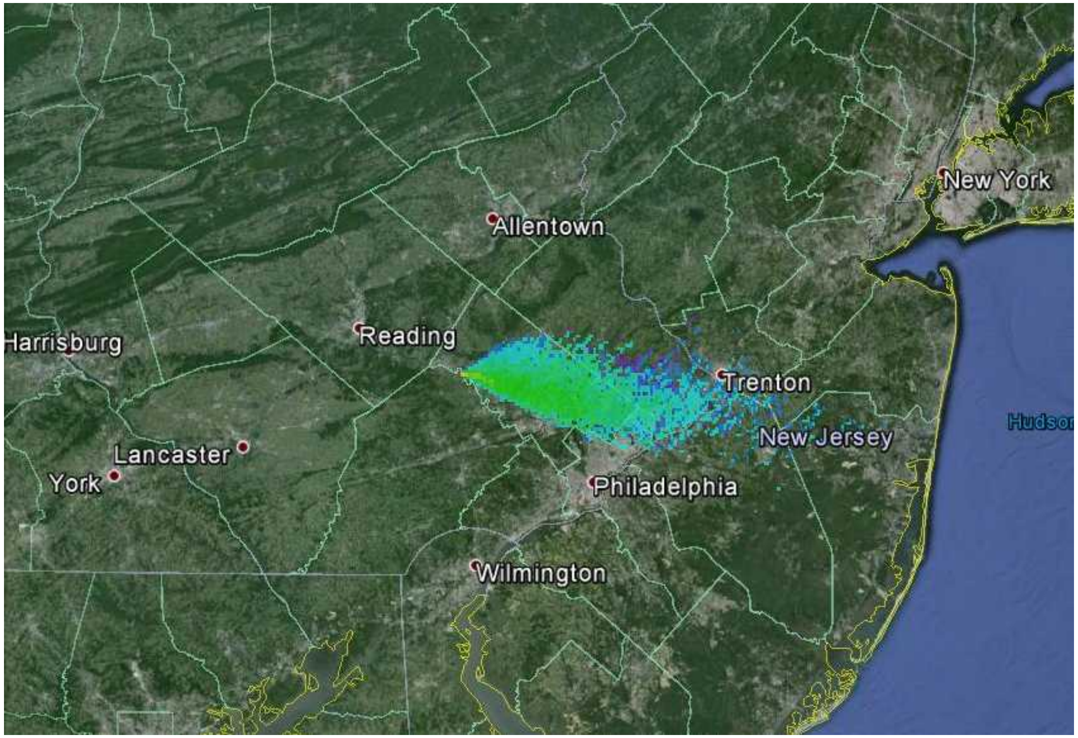
Overview

- Methods for Estimating Atmospheric Transport
- Methods for Estimating Doses
- MACCS Capabilities and Ongoing Work
- Summary



Methods for Estimating Atmospheric Transport

- Scope of discussion limited to atmospheric releases

Processes that Affect a Released Contaminant

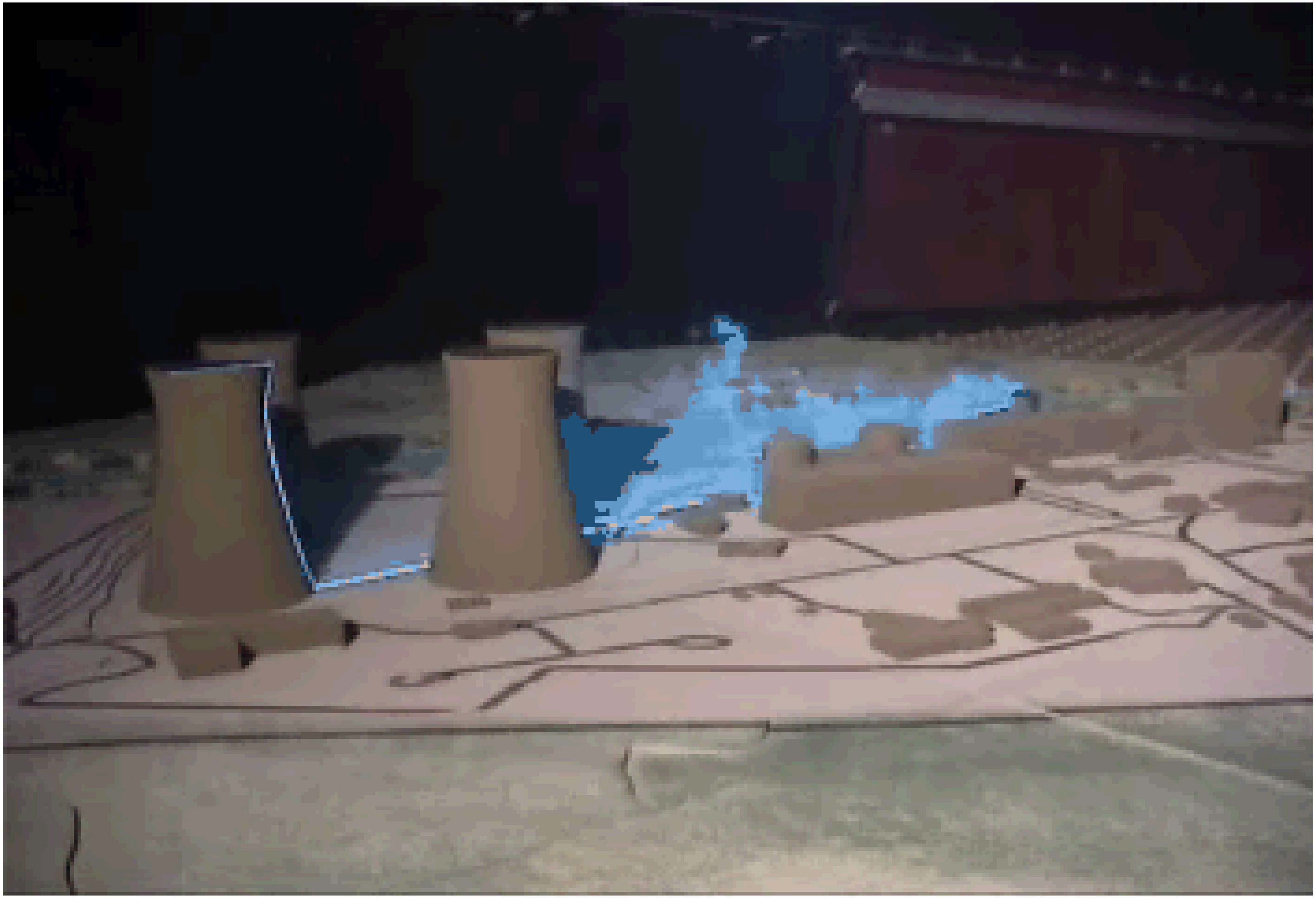
Plume transport mechanisms

- Near-field wake effects
- Buoyant plume rise
- Dilution and downwind transport
- Dispersion

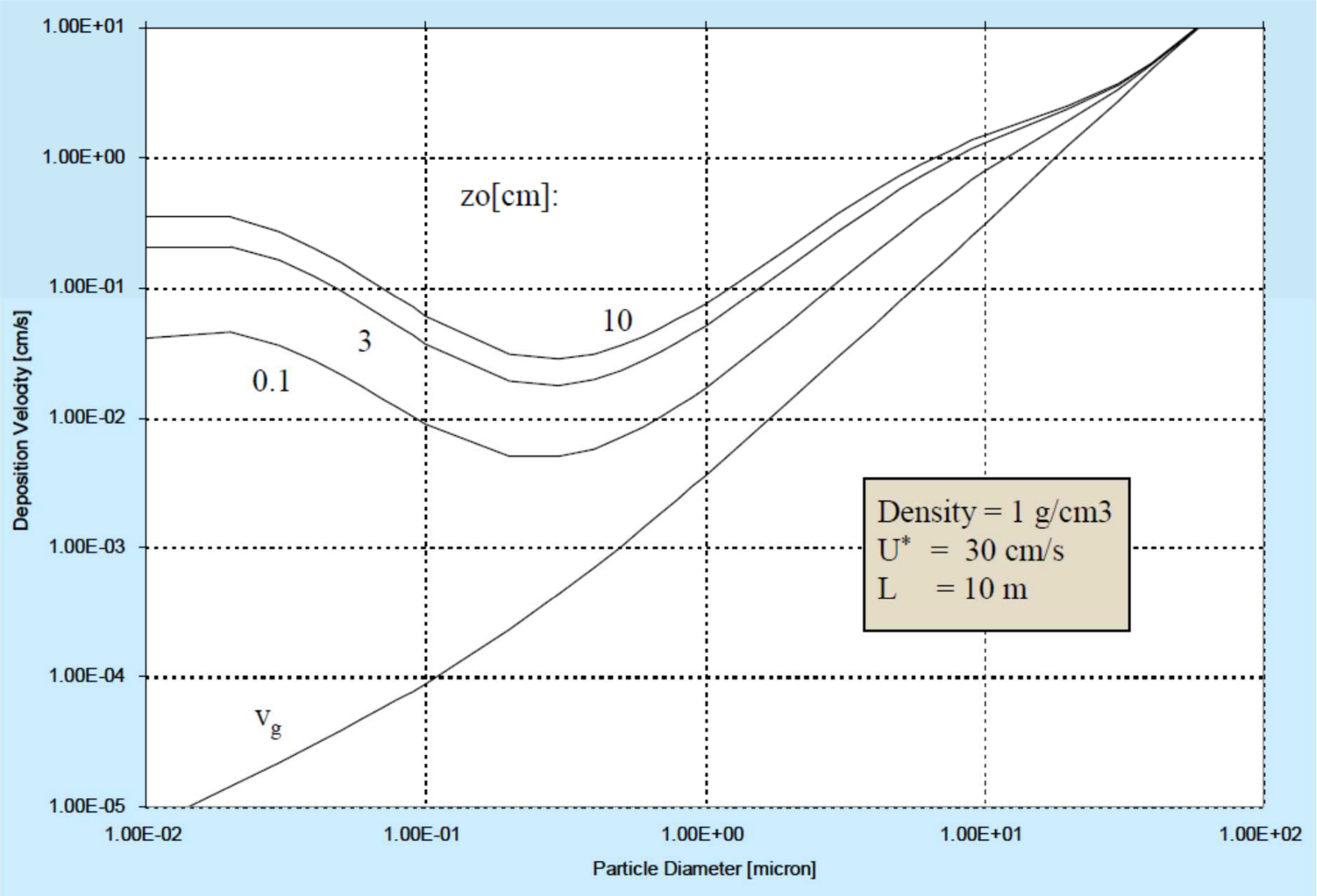
Plume depletion mechanisms

- Radioactive decay
- Wet deposition - rainout by interaction with cloud droplets and washout by falling precipitation
- Dry deposition – gradual loss of reactive vapors and aerosols by deposition onto the surface cover

Wind-Tunnel Test of Scaled Plant



Average Deposition Velocities



Wet Deposition

- Discontinuous (usually less than 10% of time) but rapid
- Can occur within and below clouds
  - Interactions within clouds is called rainout – diffusion, electrophoresis, turbulent and shear effects, etc.
  - Interactions below clouds is called washout – impaction and interception by falling rain drops
- Important parameters for washout are
  - Diameter of falling rain droplet, ice pellet, or snow flake
  - Fall velocity
  - Precipitation intensity or rate

Atmospheric Transport Inputs and Outputs

- Basic weather inputs
  - Wind speed
  - Wind direction
  - Atmospheric stability
  - Precipitation rate
- Basic outputs
  - Air concentrations
  - Surface deposition

Illustration of Gaussian Plume, Gaussian Puff, and Lagrangian Particle Models

Gaussian plume

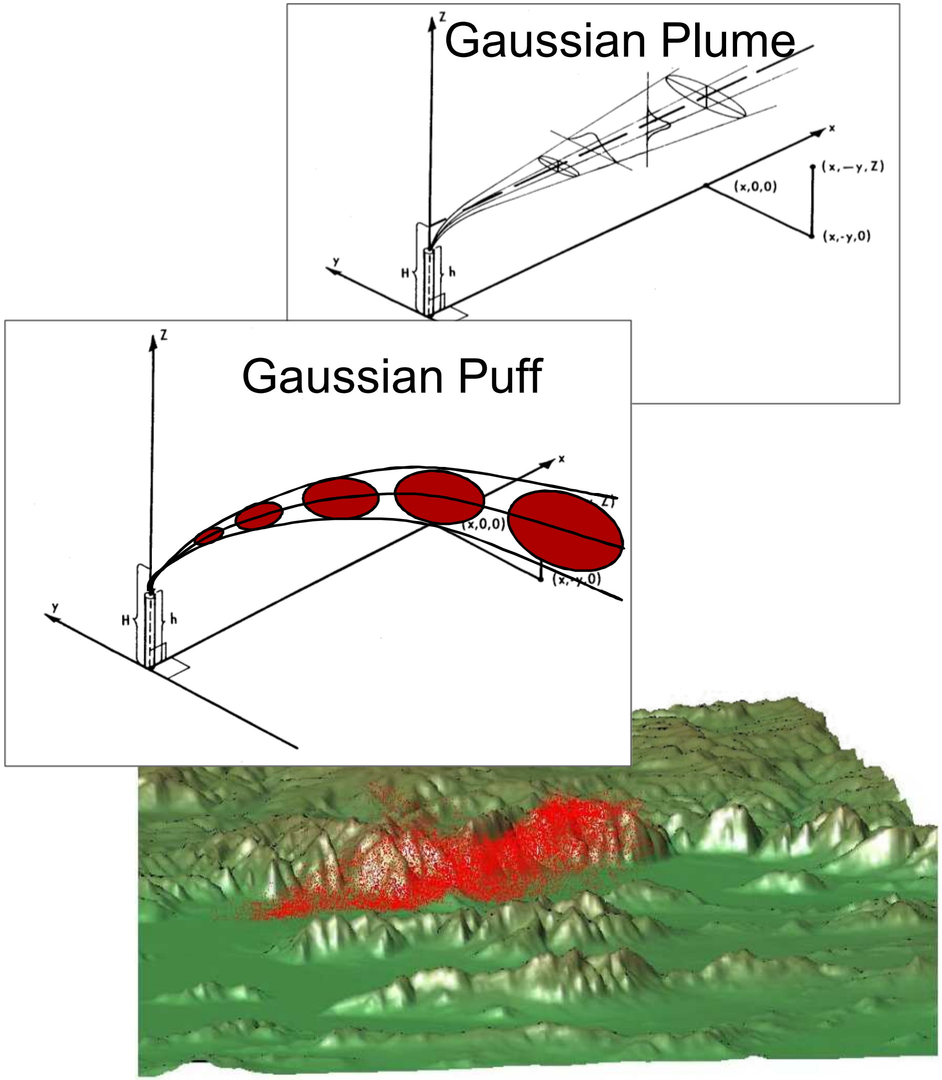
- Single tower wind field data
- Plume follows straight line
- Short computation time

Gaussian puff

- Multi-Tower or three-dimensional wind field data
- Puff follows curved paths
- Intermediate computational time

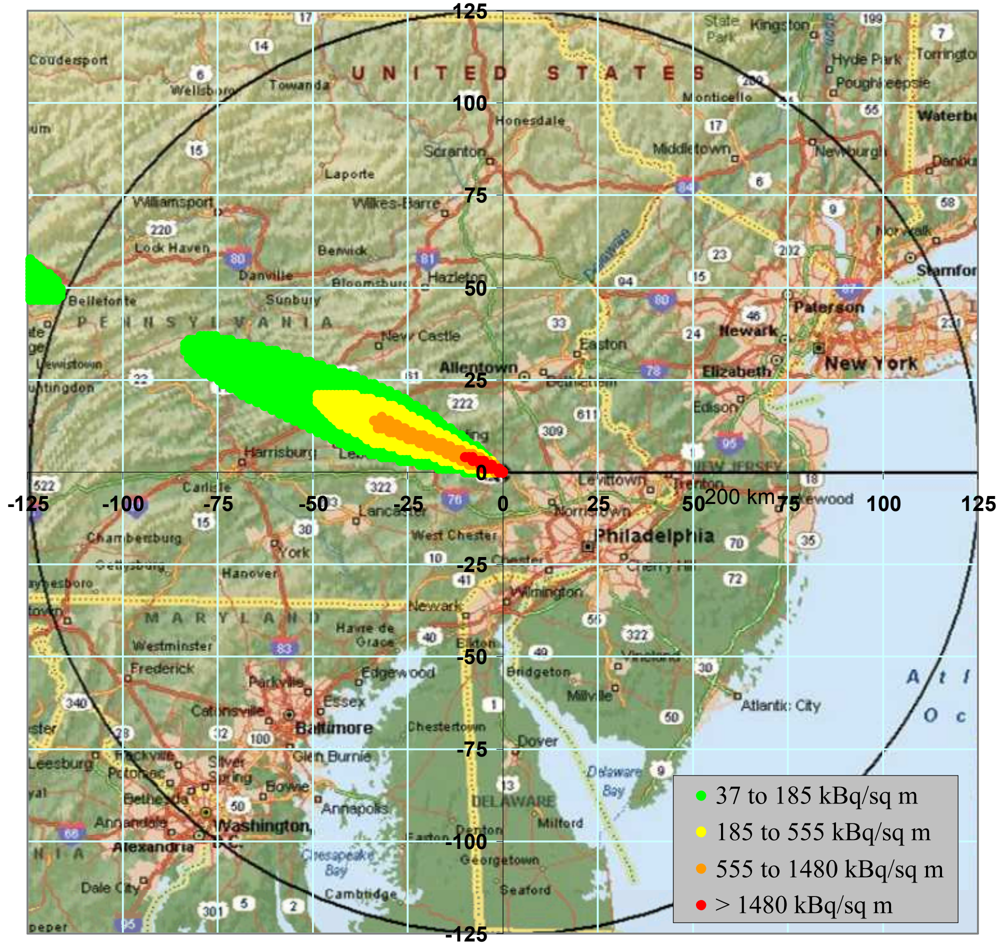
Lagrangian particle tracking

- Three-dimensional wind field data
- Individual particles follow complex paths
- Long computational time



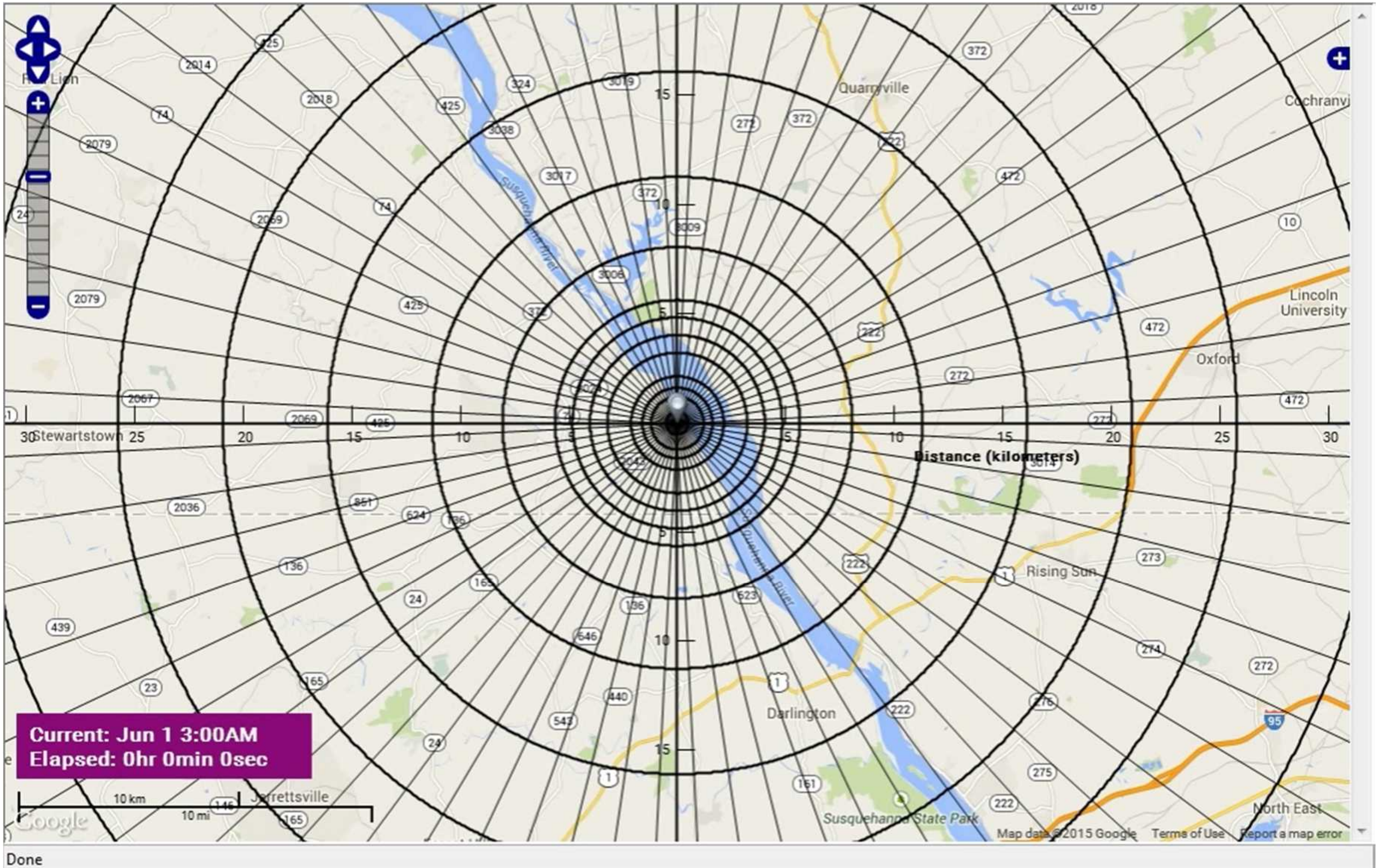
Lagrangian Particle Tracking

Deposition Pattern from Single Gaussian Plume Segment (MACCS)

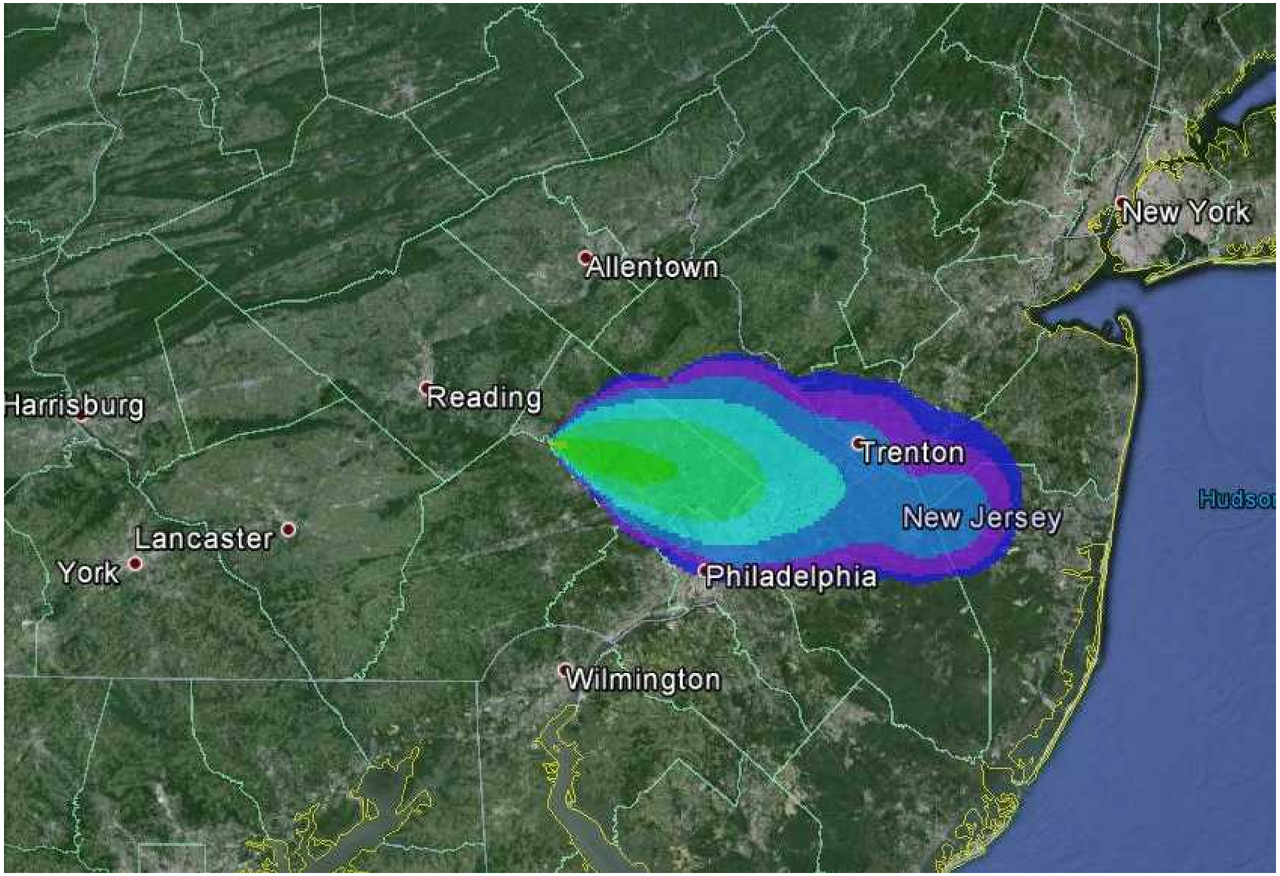


- Gaussian plume follows a straight line

Illustration of Gaussian Plume Segments

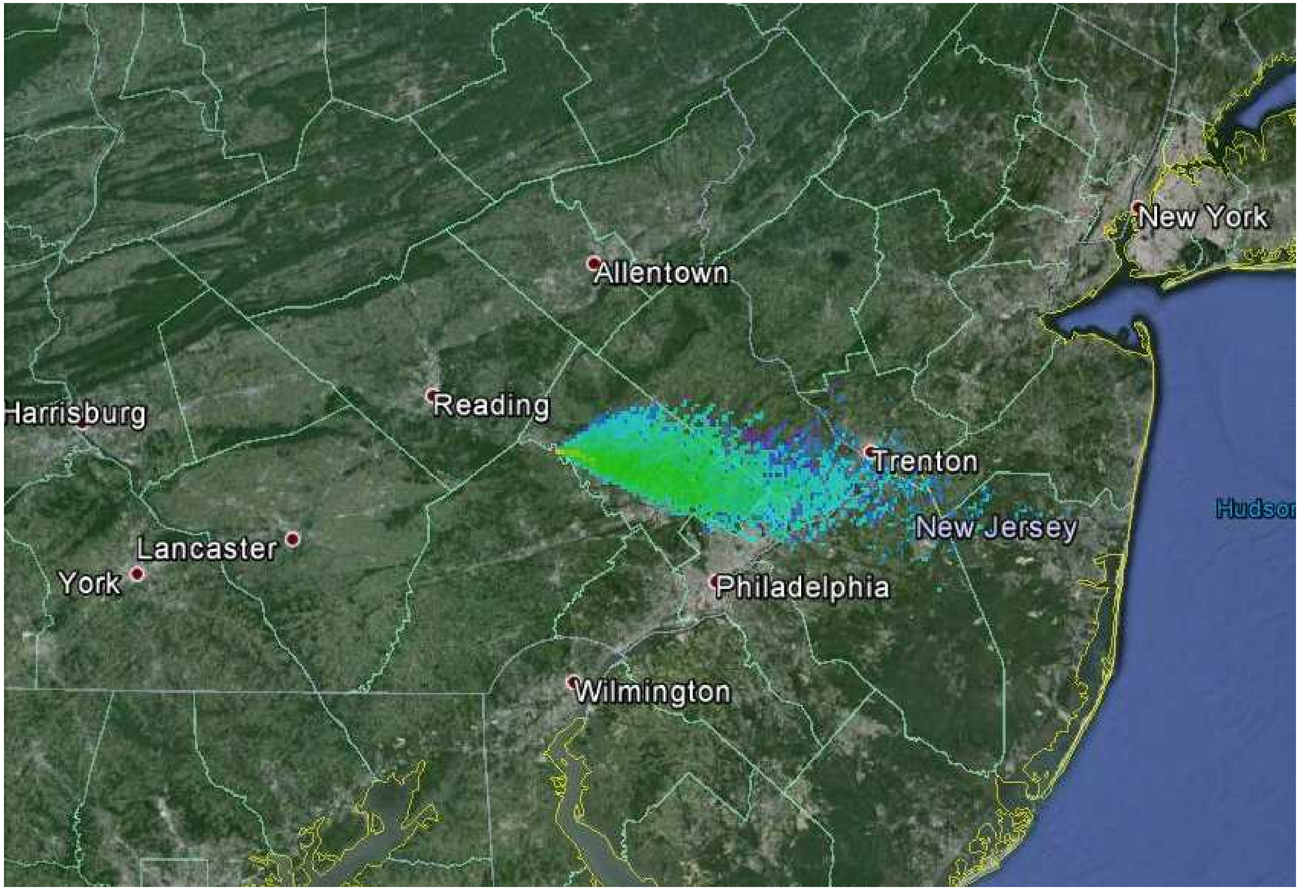


Deposition Pattern from Gaussian Puffs (HYSPLIT)



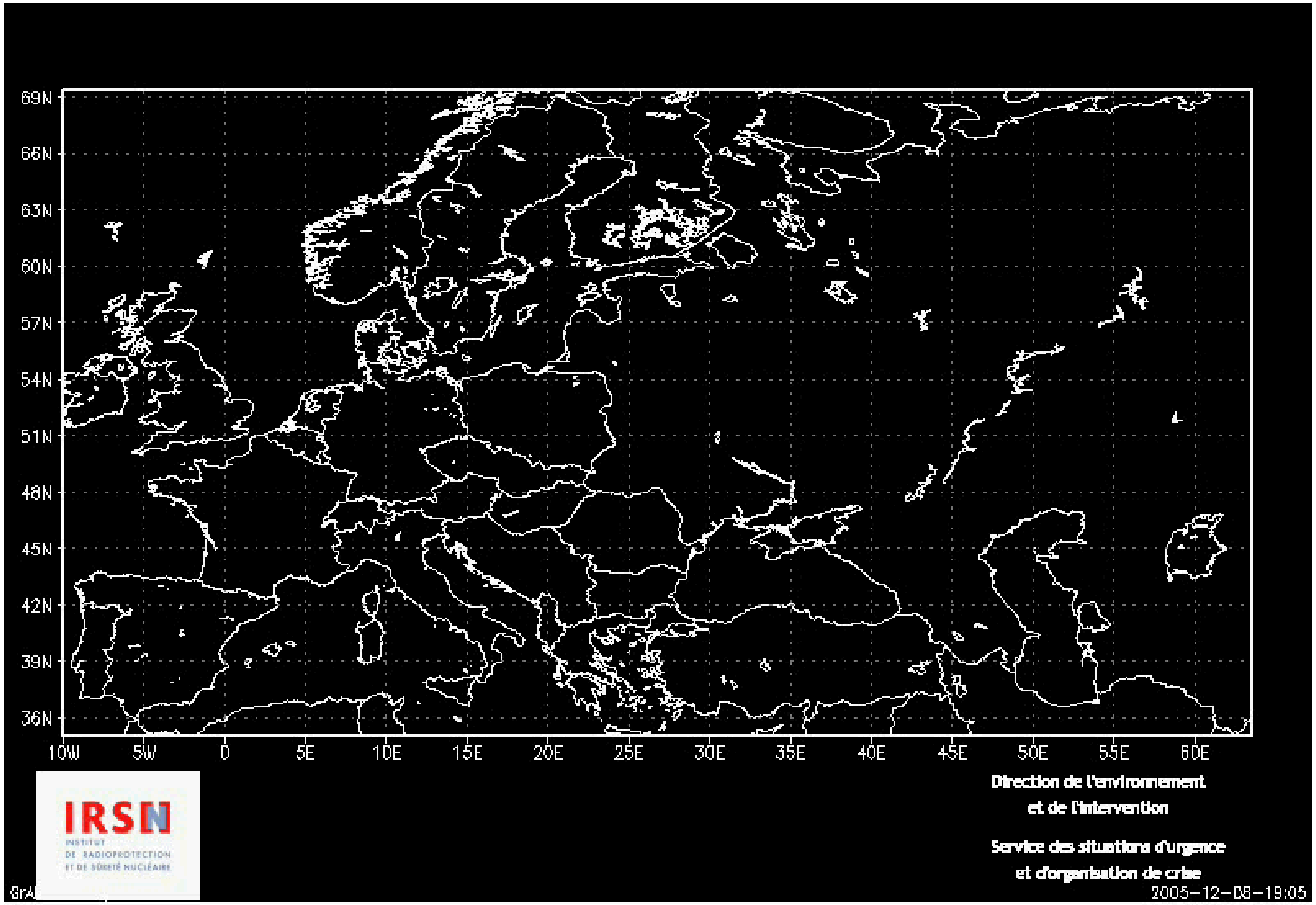
- Gaussian puff can follow a curved trajectory when wind direction changes

Deposition Pattern from Lagrangian Particles (HYSPLIT)



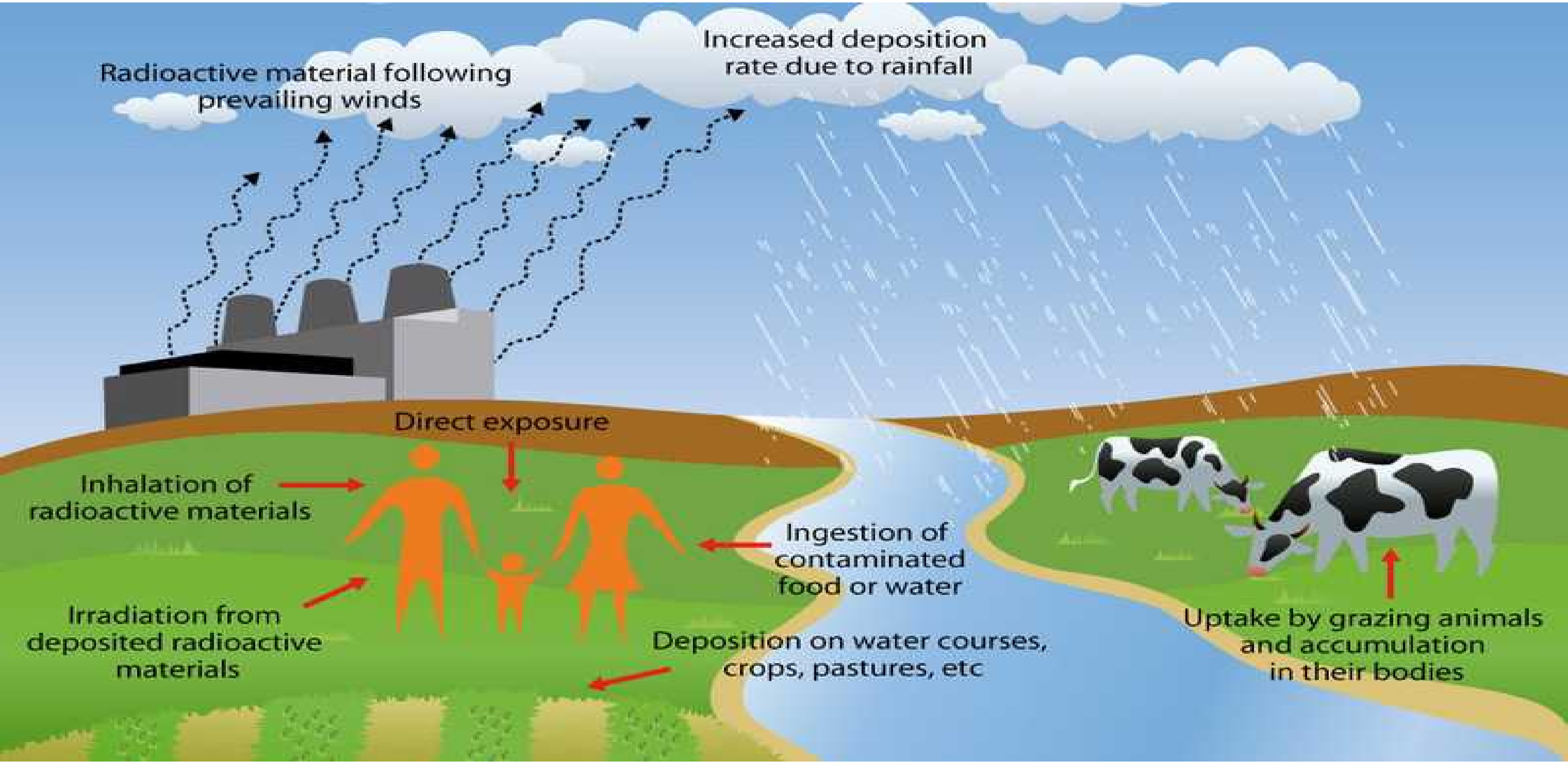
- Lagrangian particles can follow complex paths

Simulation of Chernobyl Accident



Methods for Estimating Doses and Dose Rates

Pathways to Receptors From Atmospheric Release



Dose Pathways to People

- Calculating doses begins with estimating two basic quantities
  - Time integrated air concentration, χ
  - Ground concentration, D
- Internal
  - Direct inhalation

    Dose = χ x (Breathing Rate) x DCF_{Inh}
  - Ingestion

    Dose = D x (Area Occupied by Crop) x (Transfer Factor) x (Fraction Consumed) x DCF_{Ing}
  - Resuspension inhalation

    Dose = D x (Resuspension Factor) x (Breathing Rate) x DCF_{Inh}

Dose Pathways to People (cont'd)

- External
  - Cloudshine (Immersion)

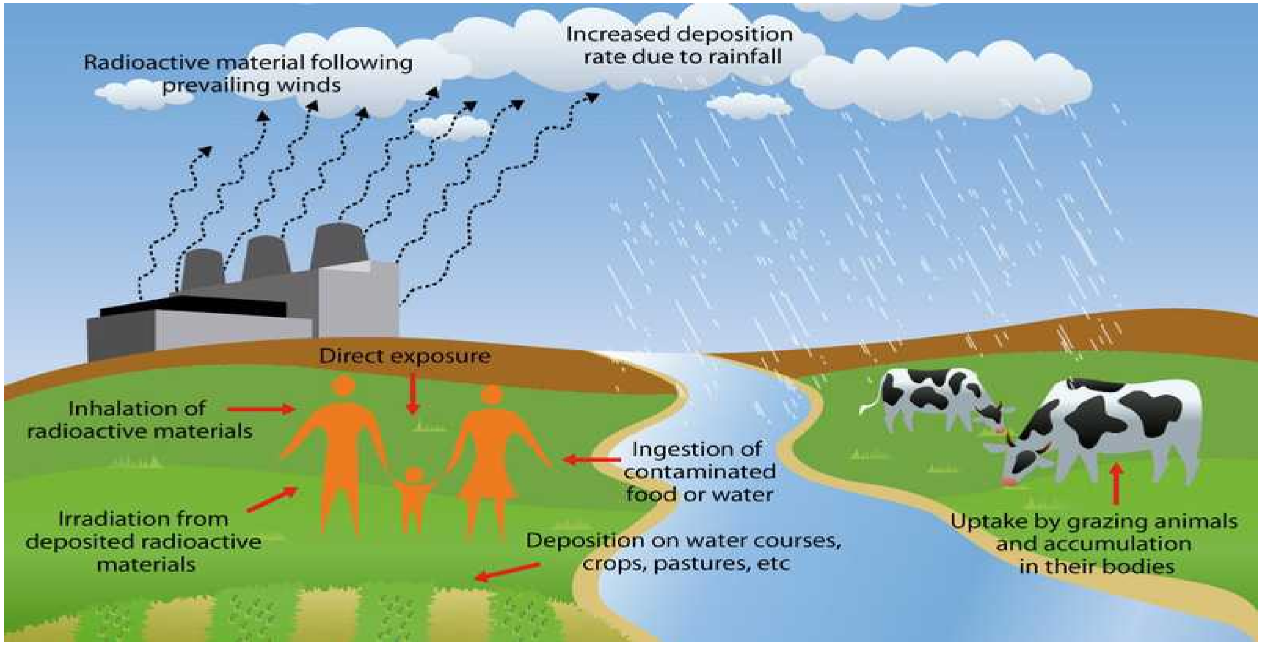
    Dose = χ x DCF_{CS}
  - Groundshine

    Dose = D x DCF_{GS}

MACCS Capabilities

MACCS Overview

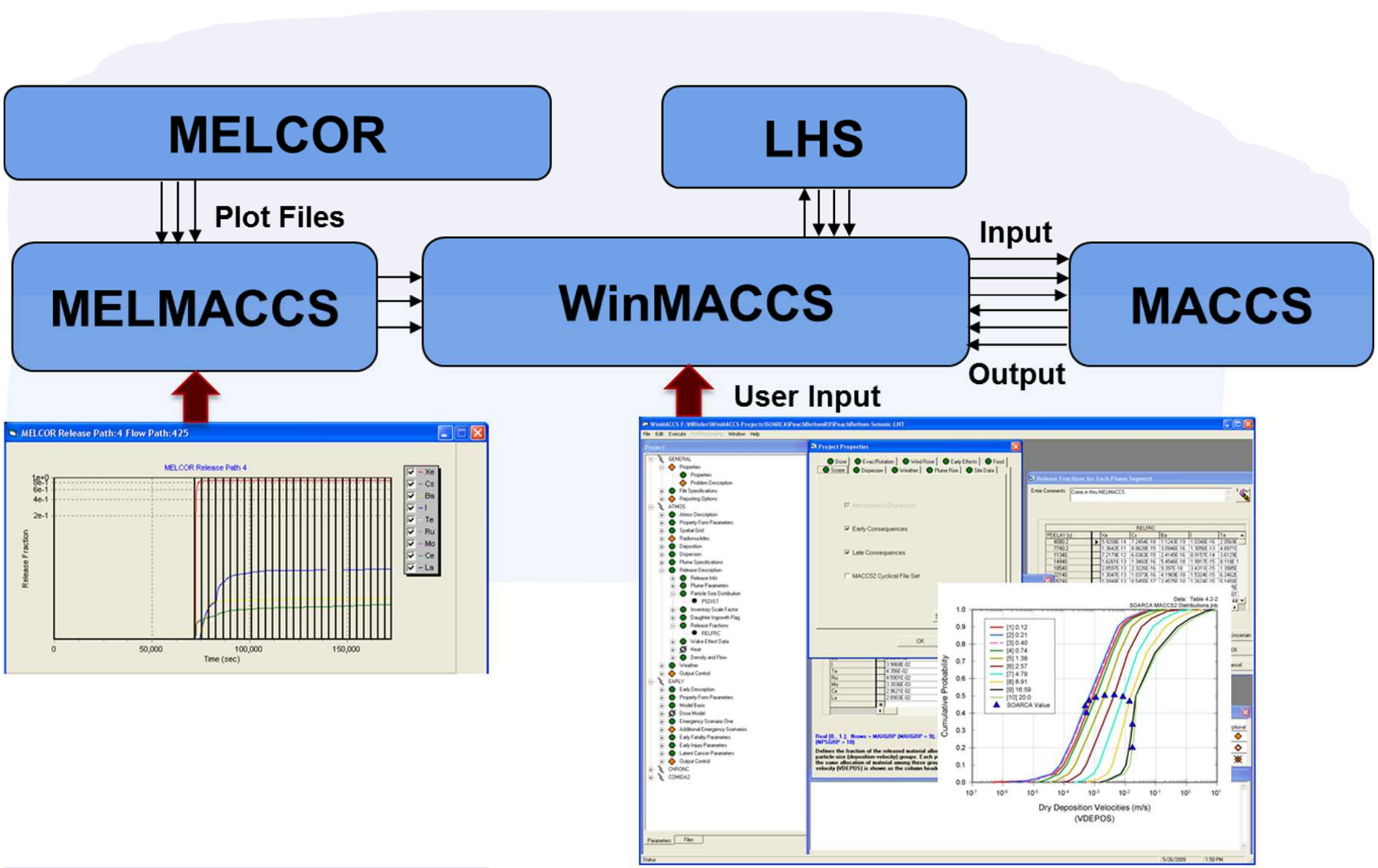
- **Atmospheric transport**
  - **Plume buoyancy**
  - **Building-wake effects**
  - **Dispersion**
  - **Trapping in mixing layer**
  - **Dry deposition**
  - **Wet deposition**
- **Dose pathways**
  - **Cloudshine**
  - **Groundshine**
  - **Inhalation**
  - **Ingestion**



Uses for MACCS Code

- MACCS is used exclusively in US for Level-3 PRAs and similar calculations
  - New licenses and license extensions (both applicants and NRC)
  - Regulatory analyses and rulemaking
  - NRC's Level-3 PRA
  - Verification of safety goals
  - Guidance for emergency planning
- MACCS is widely used internationally
  - 17 countries (Japan, Finland, Belgium, Argentina, Taiwan, South Korea, United Arab Emirates, Switzerland, Spain, Canada, Italy, Czech Republic, Poland, Croatia, Sweden, China, USA)
  - Approaching 500 users
- MACCS is used widely by DOE and DOD facilities

MACCS Calculation Framework



MACCS Estimates Consequences of Airborne Radioactive Releases

- Consequences considered by MACCS (MELCOR Accident Consequence Code System)
  - Doses from up to 150 radionuclides
  - Health effects
  - Land contamination
  - Economic impacts
- Consequences altered by mitigative actions in three phases
  - Emergency
  - Intermediate
  - Long-term

Current MACCS Modeling of Atmospheric Transport

- Radioactive decay and ingrowth of 150 radionuclides in 6 generations
- Effects of building wake
- Buoyant plume rise
- Dry deposition of 20 particle sizes
- Wet deposition
- Atmospheric dispersion using Gaussian plume segment model

First Phase

- Emergency phase
  - 1 to 40 days (typically 7 days)
  - Dose pathways
    - Direct inhalation
    - Cloudshine
    - Groundshine
    - Resuspension inhalation
    - Deposition onto skin
  - Possible mitigative actions
    - Sheltering
    - Evacuation
    - Relocation

Second Phase

- Intermediate phase
  - After end of emergency phase up to 1 year
  - Dose pathways
    - Groundshine
    - Resuspension inhalation
    - Ingestion of contaminated food/water not considered
  - Mitigative actions limited to relocation

Third Phase

- Long-term phase
  - After end of intermediate phase up to 317 years (typically 50 years)
  - Dose pathways
    - Groundshine
    - Resuspension inhalation
    - Ingestion of contaminated food and water
  - Possible mitigative actions
    - Decontamination
    - Interdiction (implies relocation)
    - Condemnation
  - Mitigative actions are based on “habitability” and “farmability” criteria with “habitability” decisions taking precedence

Important MACCS Efforts

- Code development
  - Advanced atmospheric transport model
  - Multi-source model
- Code applications
  - SOARCA uncertainty analysis for Peach Bottom and Surry
  - Participation in NRC's Level 3 PRA Project
  - Validation against Fukushima data

New Atmospheric Transport Model

- Sandia is developing a high-fidelity atmospheric transport model in MACCS based on HYSPLIT.
  - Lagrangian particle tracking
  - Gaussian puffs
- A complete MACCS model is expected by the end of 2015.
- Assessment and validation are to be completed by the end of 2016.
- A workshop is to be presented for NRC staff near the end of 2016.

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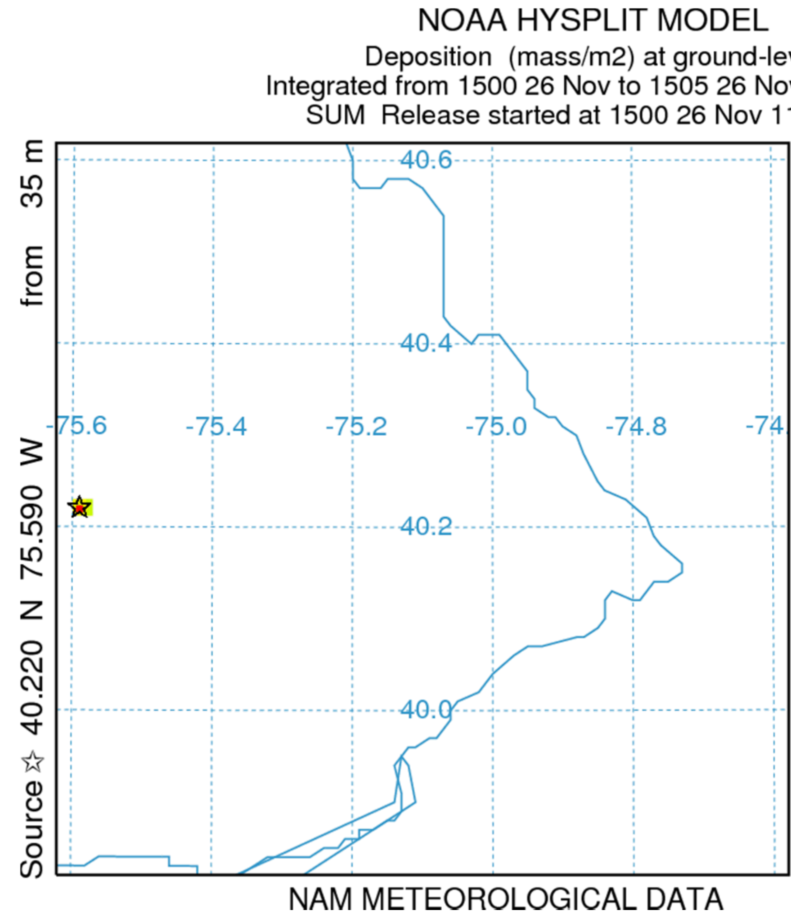
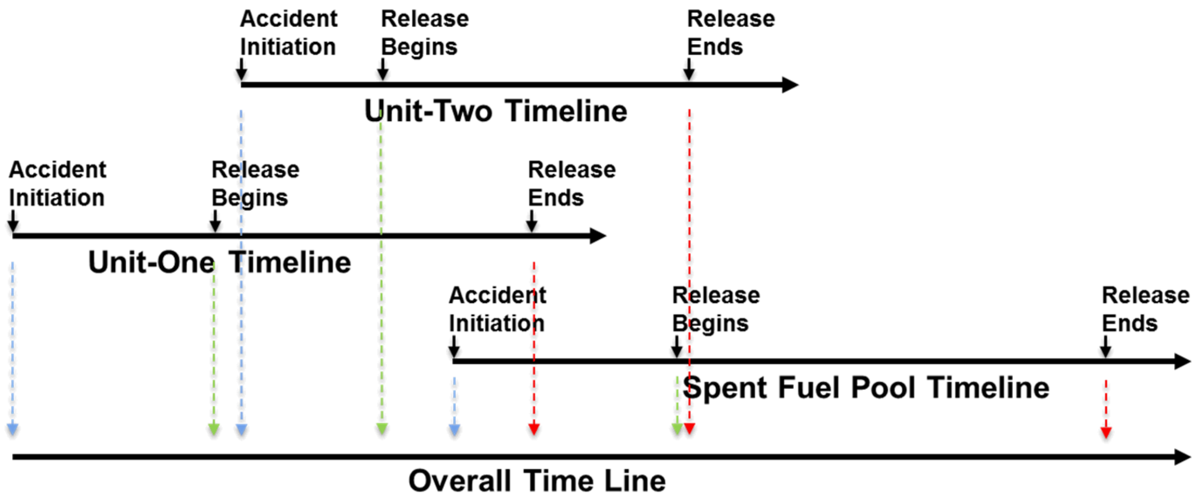


Multi-Source Model

- Sandia modified MACCS code suite to create a multi-source capability.
- A recently released version of the software incorporates this new model.
- Model is well suited for simulating the three units of the Fukushima Daiichi site that underwent severe accidents.



Summary

- Three basic types of atmospheric transport models are used to evaluate consequences
- Ground concentrations from atmospheric transport modeling are used to estimate doses and dose rates
- MACCS is a widely used tool for estimating reactor accident consequences
  - Doses and dose rates
  - Health effects
  - Ground contamination
  - Economic losses
- MACCS can estimate multi-source consequences
- MACCS is currently being modified to use an optional high-fidelity atmospheric transport model