Use of MACCS2 to Support Dispersion Protocol Options for Department of Energy (DOE) Nuclear Facility Safety Applications

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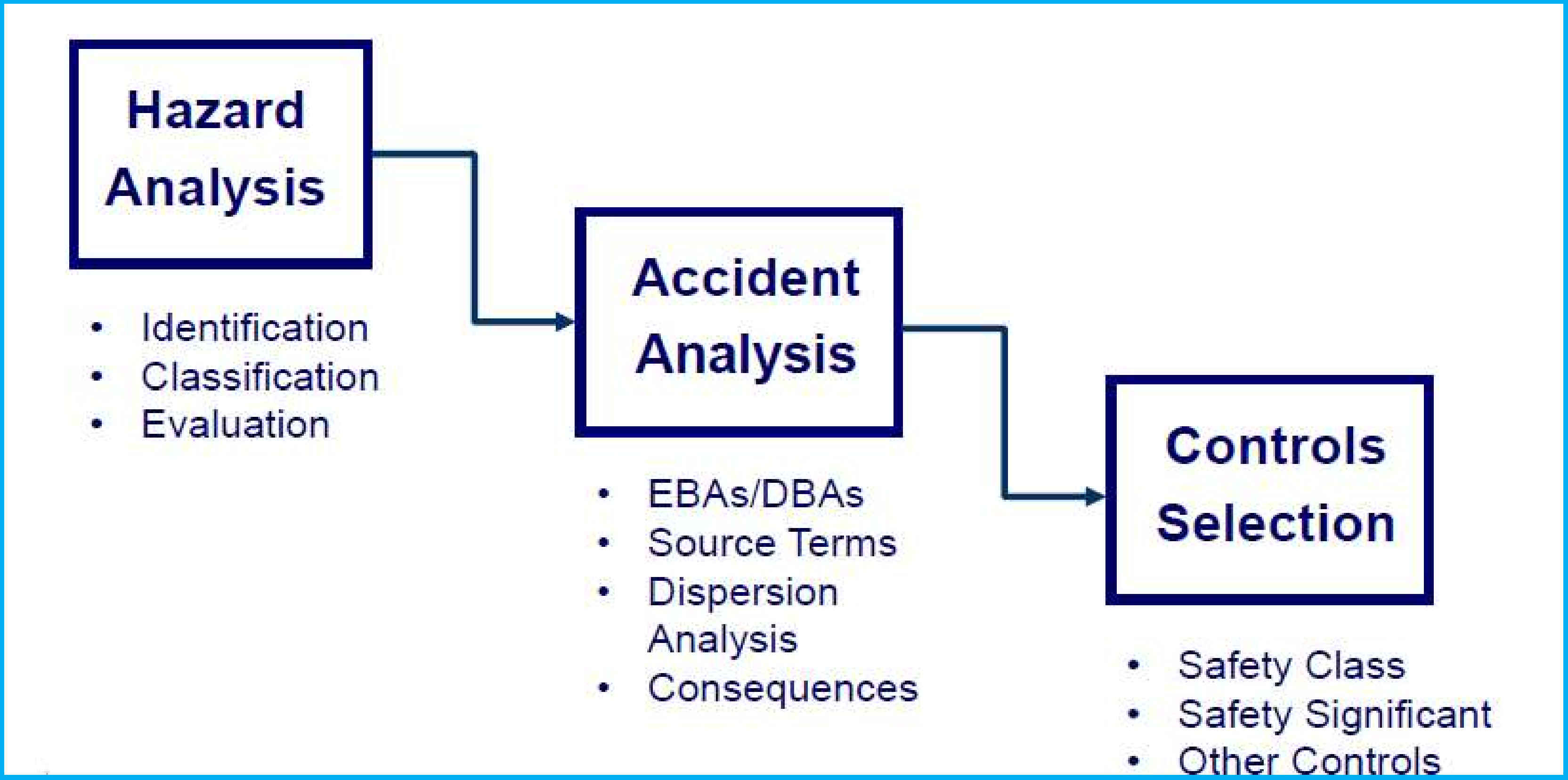
Outline of Discussion

- Overview of Documented Safety Analysis Process
- Simplified Atmospheric Transport & Dispersion Model
- MACCS2 V1.13.1 Primary Code Applied from DOE Central Registry
- Dose Quantification Process in Most DOE DSAs
- DOE-STD-3009-2014 (Preparation of Nonreactor Nuclear Facility Documented Safety Analysis) Dispersion Options
- Application of Options to SRS Site for Unit Activity Releases
  - Non-Depositing Species
  - Depositing Species
- Conclusions/Observations Regarding Three Options
- Conclusions/Observations on Use of MACCS2 for Supporting DSAs

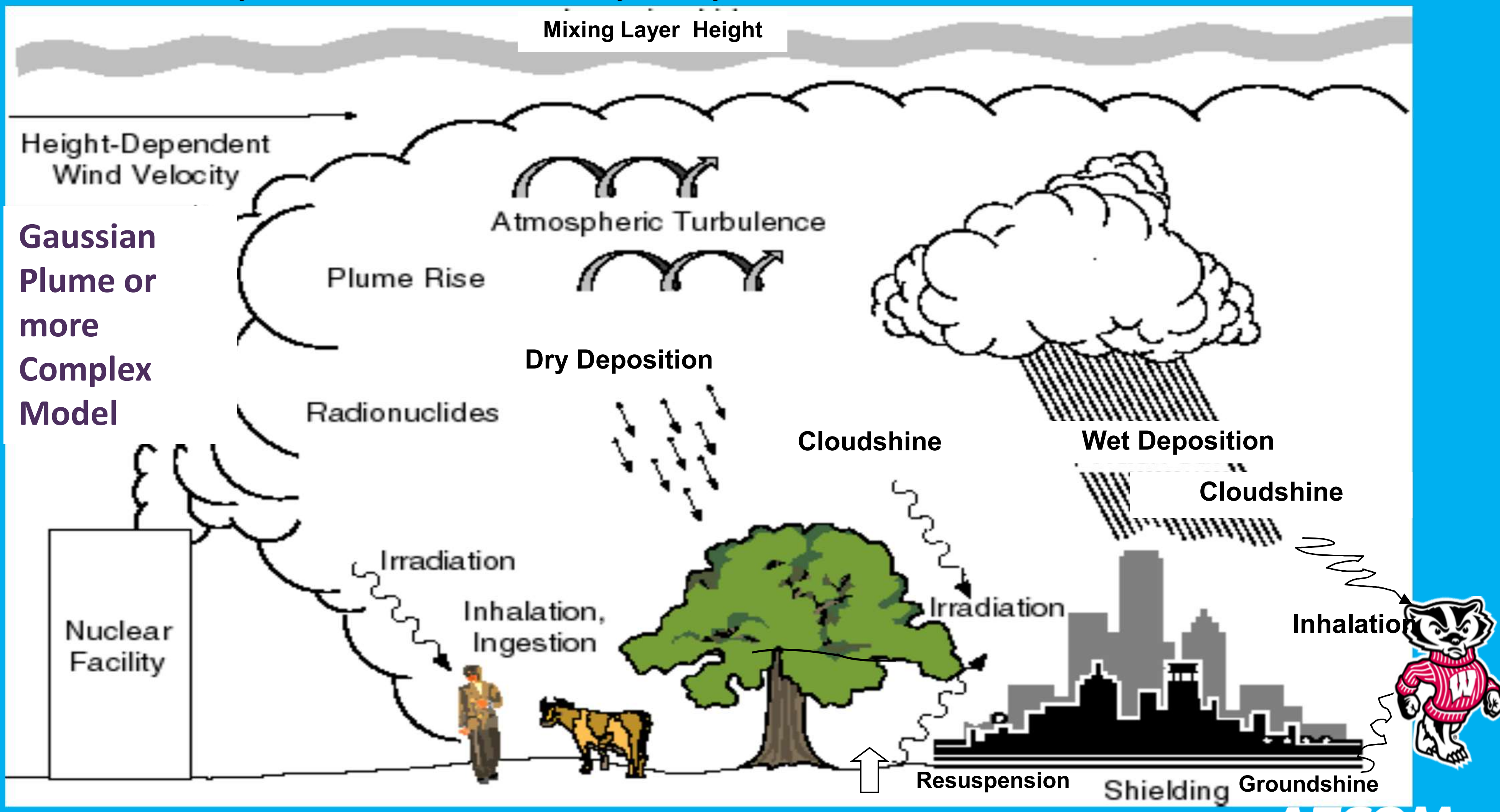
DOE Documented Safety Analysis (DSA): Hazard Identification to Control Selection



- **DOE-STD-3009-2014 standardizes the methodology for the fundamental steps in the Hazard and Accident Analysis process leading to the definition of appropriate control set for each Nuclear Facility**
- **Most DOE site and laboratories use MACCS2 to calculate the radiological consequence component**

Atmospheric Transport and Dispersion Modeling of Radiological Release in a DSA is Simplified

- **DSA process considers Acute/Early Phase Aspects of the Release**
- **Many physicochemical processes simplified in a conservative direction (models/inputs)**
- **Longer term pathways (e.g., water & food ingestion) are not considered as would be required in a full Environmental Analysis or Probabilistic Safety Analysis**



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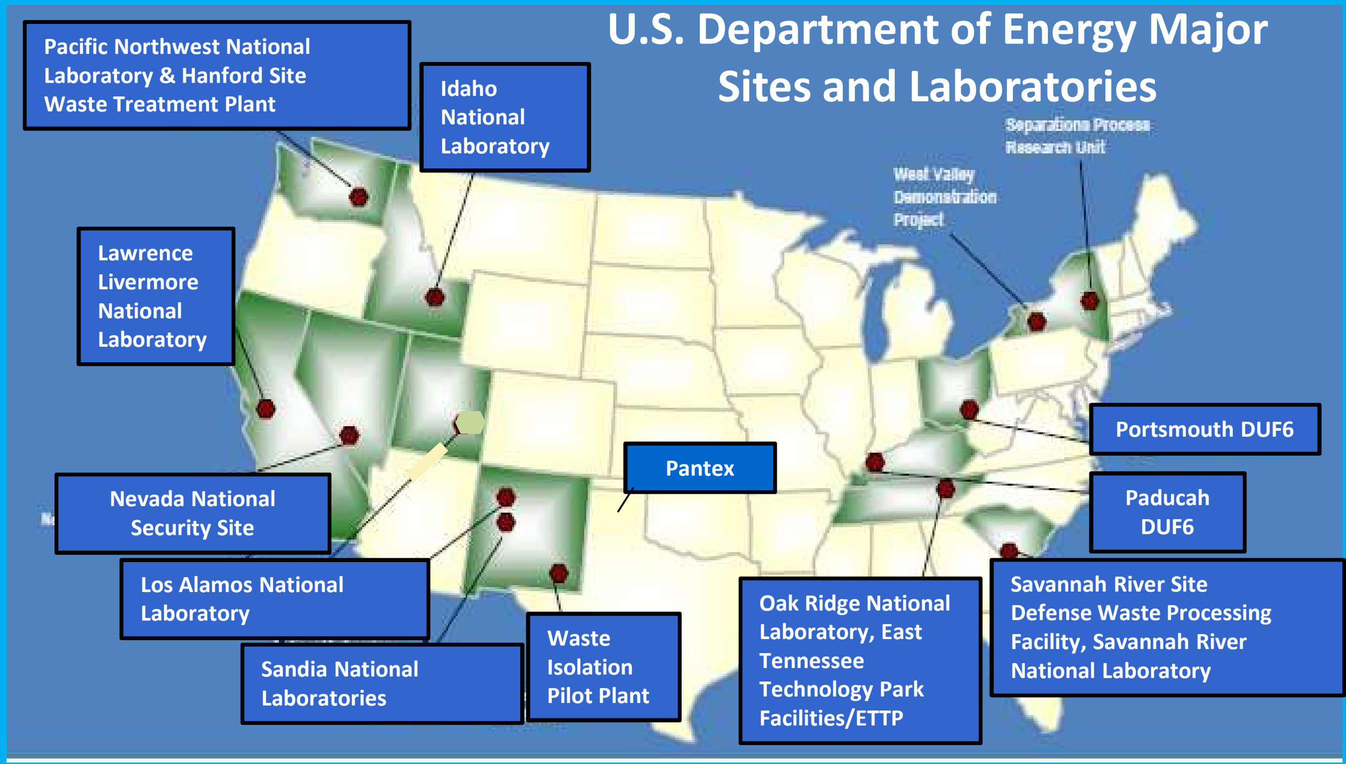
MACCS2 as Regulatory Tool for DOE Applications

- **Through early 1990s majority of DOE sites developed and applied their own Atmospheric Transport and Dispersion (ATD) software**
- **Application to many unique nuclear facility types**
- **Disparity in Software Quality Assurance (SQA) associated with software**
- **DNFSB issued Recommendation 2002-1, *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities***



- **Led to establishment of DOE Central Registry (Toolbox) in 2004**
- **Fire, In-Facility Containment codes**
- **Two Chemical Dispersion and Consequence codes**
- **Three Radiological Dispersion and Consequence codes**

DOE Central Registry ("Toolbox") Radiological ATD Software

Software	Version/ Year	Consequence Analysis Area	Owner/Developer
MACCS2 (Successor to MELCOR Accident Consequence Code System (MACCS))	1.13.1 (2004)	General radiological dispersion and consequence analysis; Acute model for tritium	Sandia National Laboratories/NRC, DOE
GENII (Second Generation of Environmental Dosimetry computer code compiled in the Hanford Environmental Dosimetry System)	V2.10.1 (2013)	General radiological dispersion and consequence analysis; both Acute and Chronic models	Pacific Northwest National Laboratory
HOTSPOT	V2.07.01 (2010)	Emergency response and emergency planning; General safety analysis; Acute model for tritium	Lawrence Livermore National Laboratory/EPA

Ref.: https://energy.gov/ehss/safety-software-quality-assurance-central-registry

Dose Quantification in Most DOE DSAs

For each postulated accident event, the dose consequence is estimated from:

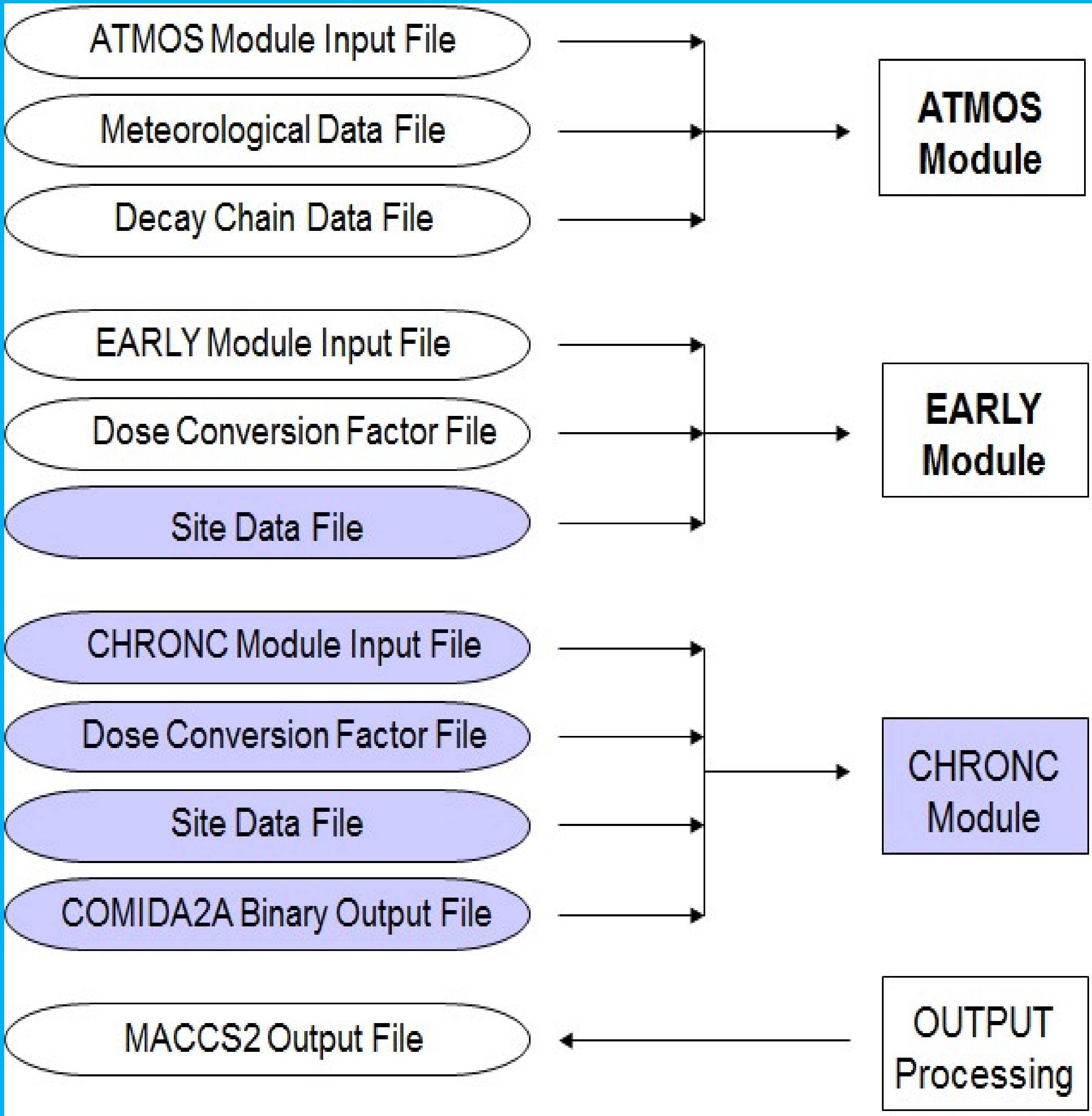
Dose (rem) = Dose (rem) = Source Term x χ/Q x DCF x BR

Where Dose =Total Effective Dose (TED) - integrated committed dose for adults, accounting for direct exposures as well a 50-y organ commitment

- **ST = Source Term (primarily tritium, strontium, cesium, and TRU)**
- **χ/Q = Atmospheric relative concentration Value (per NRC RG 1.145, Rev.1)**
- **DCF = Dose Coefficients**
- **BR = Breathing Rate**

- **Onsite DCFs: ICRP Publication 68, Dose Coefficients for Intakes of Radionuclides by Workers, and**
- **Offsite Maximally Exposed Offsite Individual (MOI): ICRP Publication 72, Age-dependent Doses to Members of the Public from Intake of Radionuclides (see also DOE-STD-1196-2011)**
- **ICRP 119 corrects minor errors in both of the above**

MACCS2 – DOE DSA Executed Modules



- Input & data files not typically used in DOE safety basis applications are shaded
- Single receptor doses with shielding and emergency action not credited
- Calculation models acute phase only (24 h)

Nuclear Facility Radiological Dose Consequences

- **DOE-STD-3009-2014 directs evaluation of the atmospheric dispersion of radionuclides in radiological source term with one of three options**
- **Option 1: NRC Reg. Guide 1.145 (*Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, Rev. 1, February 1983)**
  - **A process based on Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants***
- **Option 2: Use of DOE Central Registry software with default parameters**
- **Option 3: Site/Facility specific modeling protocol**
  - **Use of site-specific methods and parameters as defined in a site/facility specific DOE-approved modeling protocol**
- **Use of any of the above options should follow either 95th direction-independent or 99.5th percentile direction-dependent methodology for the relative concentration (i.e., dilution factor, χ/Q (s/m^3))**

Directionally-Independent (95th Percentile) or Directionally-Dependent (99.5th Percentile) Methodology

Directionally Independent Method	OR	Directionally Dependent Method
95th percentile		99.5th percentile
Reg. Guide 1.145, Section C.3, Reg. Position 3, *Determination of 5 Percent Overall Site χ/Q Value*		Reg. Guide 1.145, Section C.2, Reg. Position 2, *Determination of the Maximum Sector Values*

- Option 1: Follow NRC Regulatory Guide (RG) 1.23, Meteorological Monitoring Programs for Nuclear Power Plants
- Option 2/3: Follow RG 1.23 or EPA-454/R-99-005, Meteorological Monitoring Guidance for Regulatory Modeling Applications
- Option 3: Considers Surface Roughness Characteristics of Region of Transport

Option 1 – Regulatory Guide 1.145 Methodology

- Software-independent, and calculated through spreadsheet exercise
- Dispersion coefficients (σ_y, horizontal/crosswind direction; σ_z, vertical direction) developed according to Regulatory Guide 1.145 prescription
- Allows for plume meander to incorporate effects of low-speed winds and building effects
- Does not consider site characteristics, boundary layer phenomena, source depletion and transformation, and the potential for resuspension/re-emission
- Find additional guidance in Technical Basis for Regulatory Guide 1.145, NUREG/CR-2260

Option 2 – DOE Central Registry Software with Conservative Inputs

- Non-buoyant, ground level, point source release;
- Plume centerline concentrations for calculation of dose consequences;
- Rural dispersion coefficients;
- Deposition velocity of 0.1 cm/s for unfiltered release of particles (1-10 μm Aerodynamic Equivalent Diameter), 0.01 cm/sec for filtered particles, or 0 cm/s for non-depositing tritium/noble gases;
- Assume surface roughness length (z_o) of 3 cm (~Prairie Grass tests);
- Minimum wind speed of 1 m/s;
- Plume meander may be used, consistent with the accident release duration and the appropriate code guidance; and
- Building wake factors not be credited in the plume dispersion, outside of those already incorporated into plume meander.

Option 3 – Site-Specific Method & Parameters Defined in Site/Facility Specific DOE-Approved Modeling Protocol

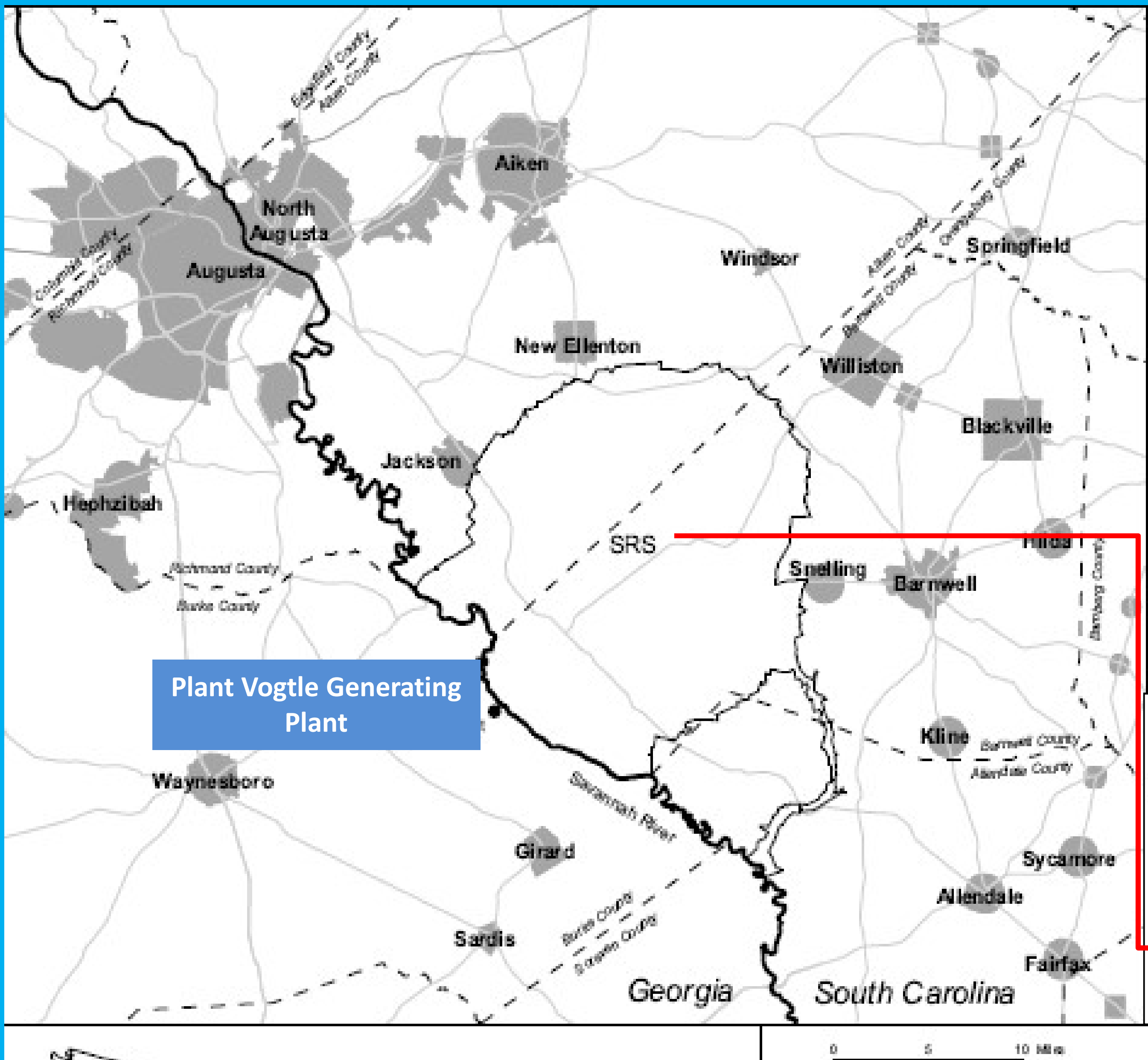
- Apply DOE Central Registry Code and DOE-approved methods, where possible
- May apply non-Central Registry software if requirements of DOE O 414.1D are met
- May model accidents with unique dispersion characteristics
  - Option 3 application illustrated in the following, uses z_o of 160 cm to adjust the reference vertical dispersion coefficients ($\sigma_{z,ref}$) with 3 cm as the reference surface roughness length ($z_{o,ref}$)
  - American Meteorologist Society (AMS) correlation to adjust

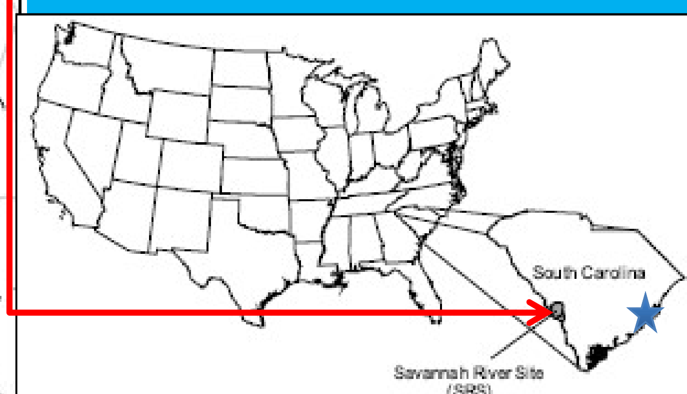
    $\sigma_z = \sigma_{z,ref} \times (z_o / z_{o,ref})^{0.2}$
- Most DOE sites/facilities are following this option
- Option allows use of more complex model(s) to inform parameter selection (e.g., deposition velocity)

Application of DOE-STD-3009-2014 Options

- Illustration application of dispersion protocol options
- Savannah River Site region of transport characteristics
- Meteorology drawn from nearby Vogtle Electric Generating Plant (VEGB, or Plant Vogtle)
- Ground-level unit activity releases, and evaluate TED at 1000 m to 10,000 m
- Two radionuclide types:
  - Non-depositing species (tritium)
  - Depositing species (plutonium)

Meteorological Data and DOE Site Characteristics





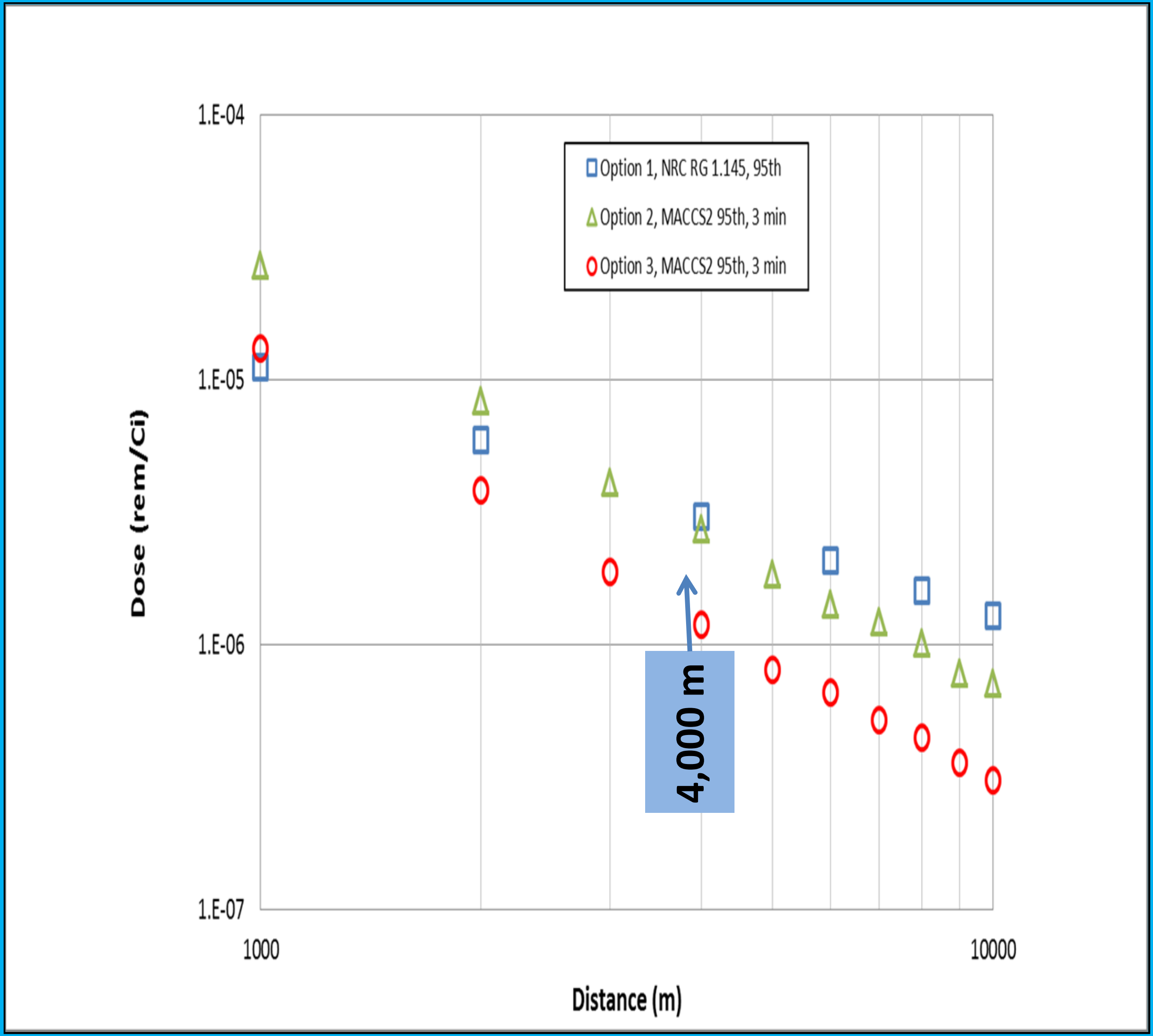
- **Apply meteorological data from Plant Vogtle (2 PWR units & 2 AP1000)**
- **Land use and topographical characteristics are those of the Savannah River Site**
  (Pine and hardwood forests interspersed with nuclear facility clusters)

Comparison of Key Modeling Attributes Among Three Options

Model Attribute	Option 1 (RG 1.145)	Option 2/3 (MACCS2)	Comment
Stability Classes	A through G	A through F	MACCS2 treats G stability as F stability
Set of Dispersion Coefficients	Eimutis-Konicek (E-K)	Tadmor-Gur (T-G)	E-K supports G stability class; T-G is default set for MACCS2. Both the E-K and T-G set of dispersion coefficients are based on 3-cm surface roughness and 3-minute averaging time.
Source Roughness	3 cm	Option 2: 3 cm Option 3: 160 cm	NRC RG 1.145 methodology does not provide an algorithm for adjusting σ_z for surface roughness.
Plume Meander Model	NRC Model	Averaging Time Model	3 minutes used as averaging time for Option 2 and 3 baseline cases; a sensitivity case for Option 3 uses 2 hours
Deposition Velocity (Non-Depositing Species)	Not Applicable	0 cm/s	Non-depositing (e.g., noble gases, tritium)
Deposition Velocity (Depositing Species)	Not Applicable	Option 2: 0.1 cm/s Option 3: 0.71 cm/s	Options 2 and 3 allow for plume depletion from deposition for particulate releases
Minimum Wind Speed	0.1 m/s	0.5 m/s	The wind speed in the meteorological data file has a minimum wind speed of 0.1 m/s.

Unit Total Effective Dose for Representative Non-Depositing Species Under the Three Options

- All base results are reported at 95th percentile
- At 1000 m, the lower Option 1 results reflect the effects of the NRC plume meander factor
- At larger distances, the Option 1 doses are the highest due to the use of a lower minimum wind speed and consideration of G stability
- Option 3 dose results consistently lower than the Option 2 results by a factor of 2.2 reflecting the higher σ_z values



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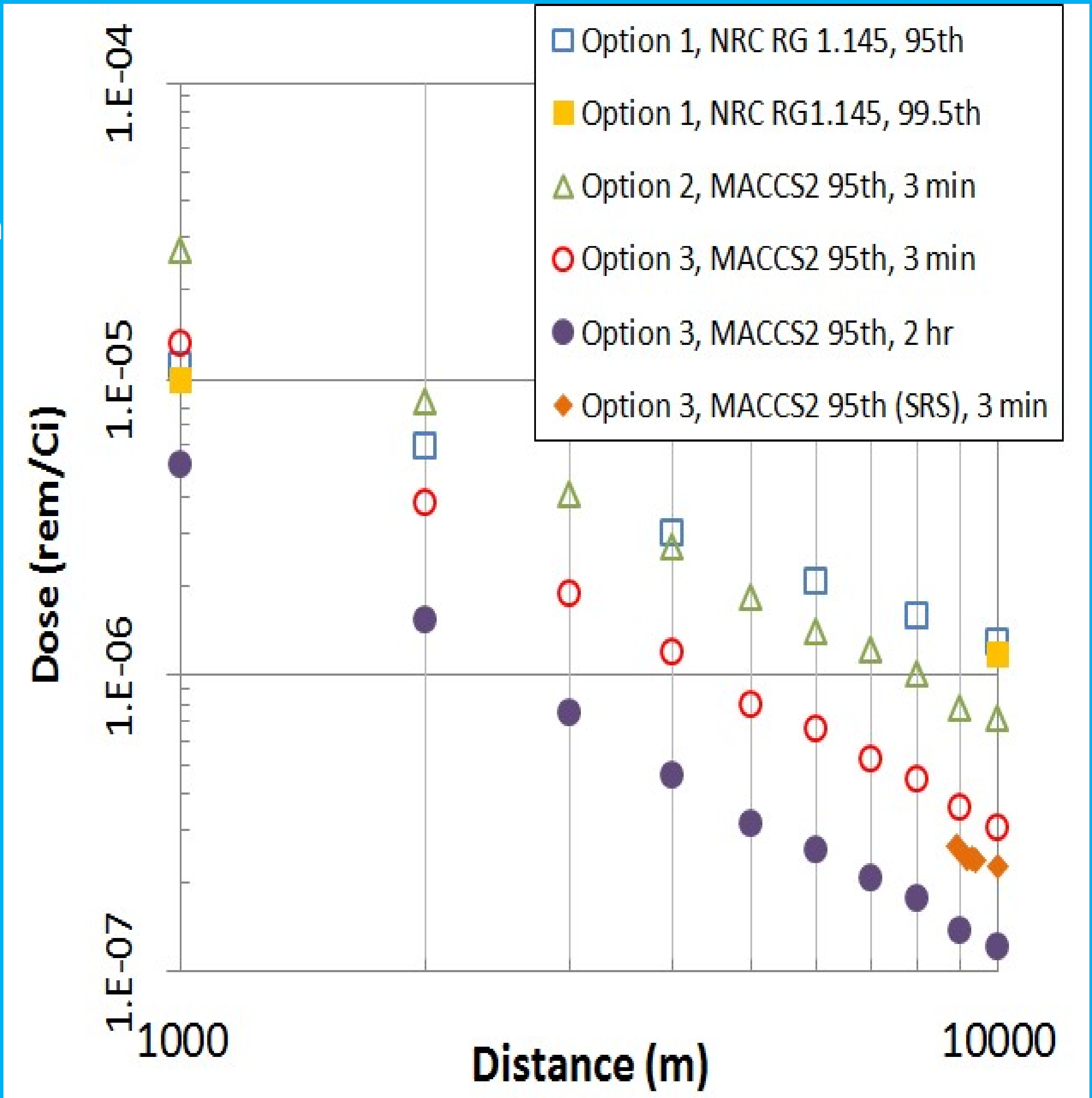
Expanded Set of Unit Total Effective Dose Results for Non-Depositing Species

- Option 1 results using the 99.5th directionally-dependent approach produced results are approximately 10% lower than the 95th directionally-independent
- Option 3 results with an averaging time of 2 hours are lower than the Option 3 results with an averaging time of 3 minutes by a factor of 2.5 reflecting the higher σ_y values
- SRS Results reflect EPA method for stability class
- Plant Vogtle results reflect NRC RG 1.23 method (DT values) for stability class determination



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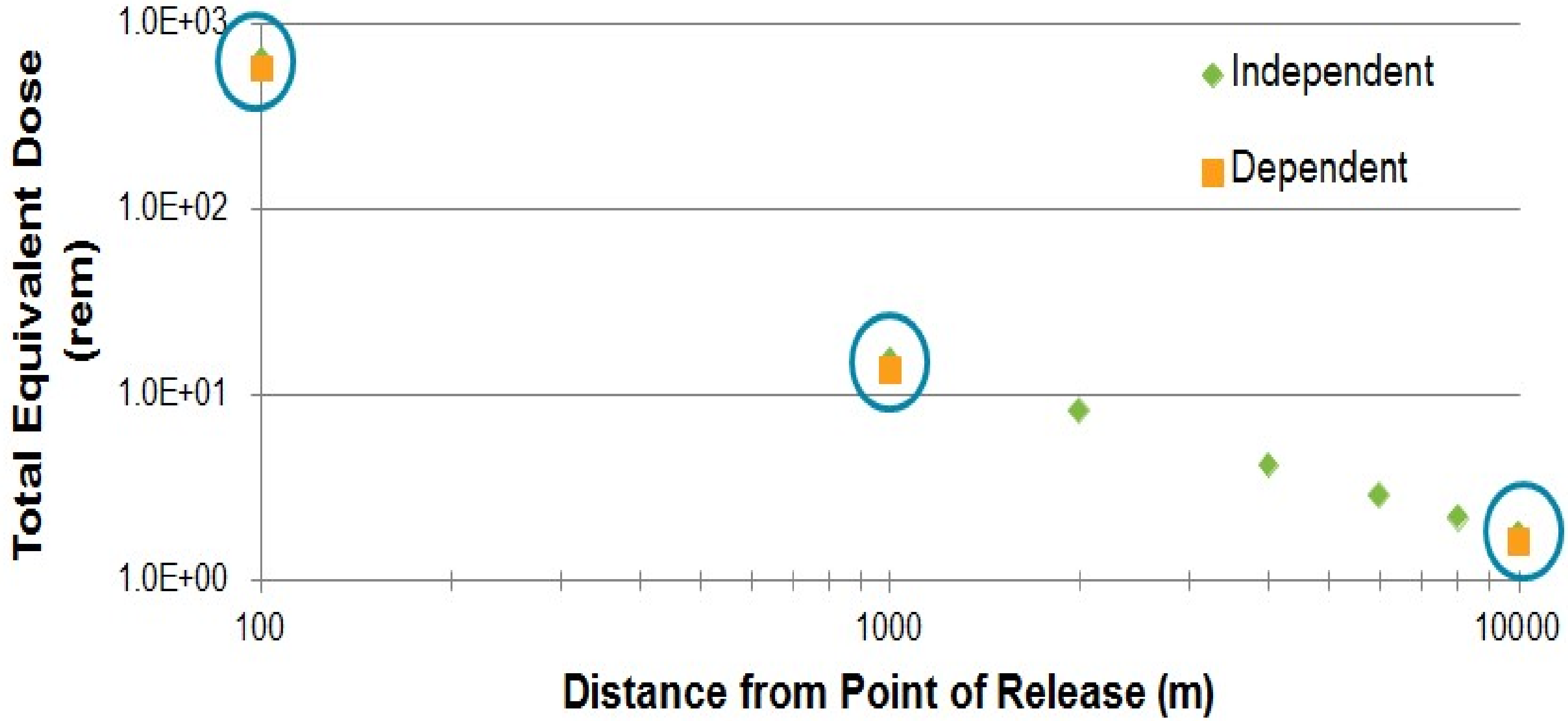
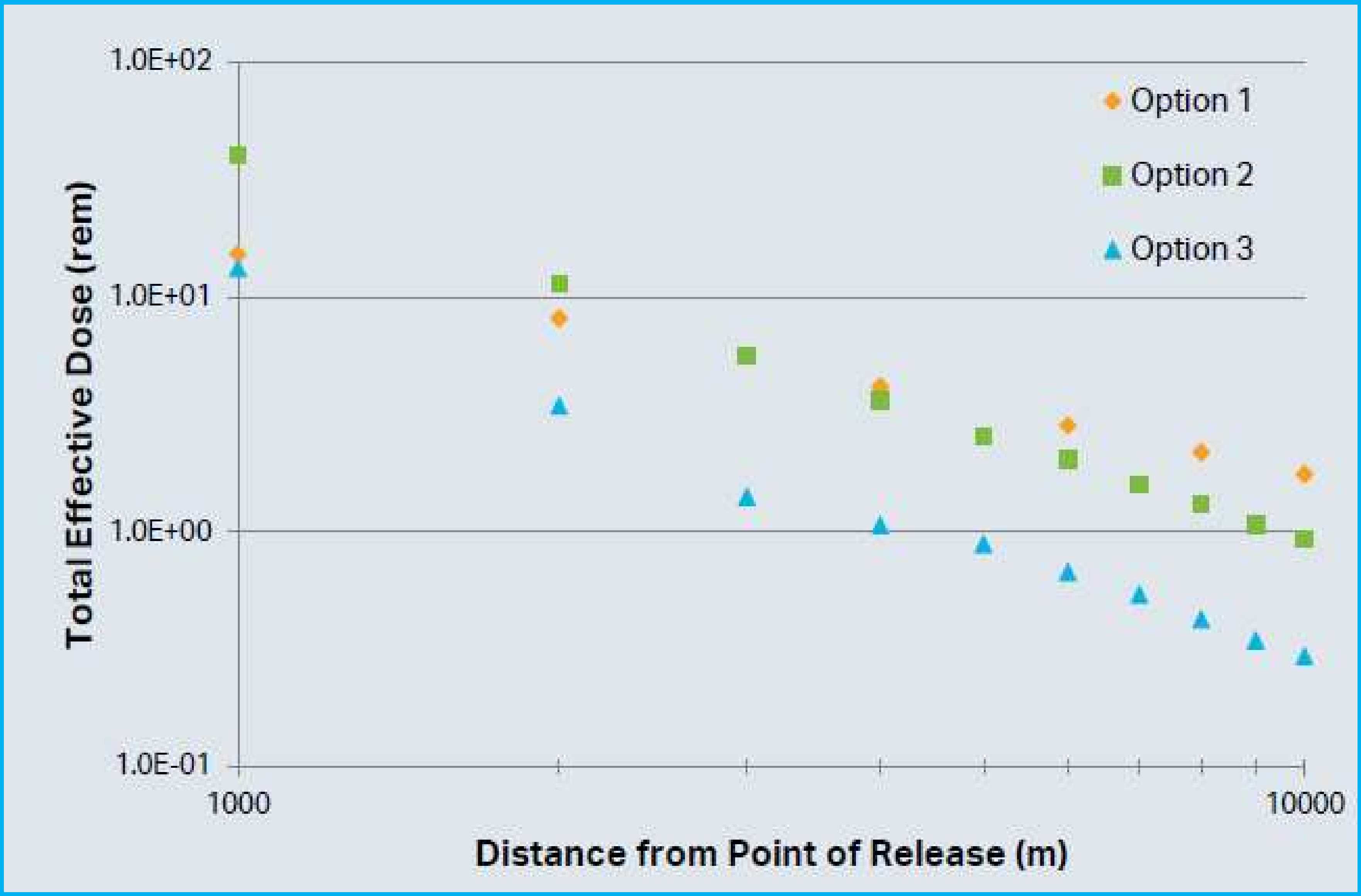
Option 1 Direct-Dependent and Independent Results – Depositing Species



Method	Distance 100 m	1000 m	10,000 m
Independent (95th)	642	15.3	1.76
Dependent (99.5th)	577	13.6	1.60
Percent Difference	10%	11%	9%

Expanded Set of Unit Total Effective Dose Results for Depositing Species



Conclusions/Observations - 1

DOE-STD-3009-2014 Dispersion Protocol Options using VEGP meteorological data and SRS region of transport characteristics

- Options 1 and 2 are driven by site meteorology
- Option 1 results using the 99.5th directionally-dependent approach produced results are approximately 10% lower than the 95th directionally-independent for both non-depositing & depositing species cases
- At 1000 m, the lower Option 1 results reflect the effects of the NRC plume meander factor
- At larger distances, the Option 1 doses are the highest due to the use of a lower minimum wind speed and consideration of G stability (cross-over distance ~4 km)
- Option 3 dose results consistently lower than the Option 2 results by a factor of 2.2 reflecting the higher σ_z values, higher deposition velocity (with depositing species case)

Conclusions/Observations - 2

- MACCS2 is predominant software applied in DOE Complex for the Safety Basis documentation support the licensing of Nonreactor Nuclear Facilities
- Applied in prescriptive manner following DOE-STDF-3009-2014 guidance
- Limited to acute period and applies fraction of capabilities of 2004 vintage MACCS2 (executed through ATMOS-EARLY)
- Applicable to Options 2 and 3 of DOE-STD-3009-2014 Dispersion Modeling Protocol
- From regulatory perspective, higher-hazard facilities generally invest requisite resources to meet requirements for Option 3
  - Preferred option with most DOE sites and laboratories
- Recommend staged implementation when replacing V1.13.1 in Central Registry with current or future version of WinMACCS/MACCS

Thank you for your attention – Questions?

Acronyms

ATD	Atmospheric Transport and Dispersion
BR	Breathing Rate
DCF	Dose Conversion Factor
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DSA	Documented Safety Analysis, a DOE Nonreactor Nuclear Facility Safety Analysis Report
ICRP	International Commission on Radiological Protection
MOI	Maximally Exposed Offsite Individual (public receptor)
VEGB	Vogtle Electric Generating Plant