Session III – Accident Analysis

Session III Overview

- **DOE-STD-3009-2014, Section 3 provides detailed Accident Analysis criteria and guidance**
- **Clarifies requirements, adding "shalls" to CN3 guidance**
  - See handout "DOE-STD-3009-2014 Requirements Table"
  - Red font on slides highlight requirements if not already obvious

Session III Overview (Cont.)

- **Session III Accident Analysis Topics:**
  - **Introduction (3.2, 3.2.1)**
  - **Unmitigated and Mitigated Analysis (3.2.2, 3.2.3)**
  - **Consequence Calculations (3.2.4)**
    - Radiological Source Term (3.2.4.1)
    - Radiological Consequence Calculations (3.2.4.2)
    - Chemical Consequence Calculations (3.2.4.3)

Accident Analysis Major Changes

- Clarifies requirements for unmitigated analysis
- Clarifies requirements for mitigated analysis
- NEW Provides requirements for use of PRA calculations
- Recommends use of "challenging the EG" concept for considering safety-class controls
- Clarifies use of bounding parameters in conservative consequence calculations
- Clarifies methods for Radiological Dispersion Analysis
- NEW Provides methods for Chemical Dispersion Analysis

Accident Analysis Key Requirements

- **Formal characterization of a limited subset of accidents, and determination of consequences and hazard controls:**
  - Design Basis Accidents (DBAs) – new facilities, major modifications
  - Evaluation Basis Accidents (EBAs) – existing facilities (Section A.6)
- **For identifying SC SSCs, estimated consequences to the MOI are compared to the Evaluation Guideline (EG).**
- **Accident analysis is not necessary if unmitigated offsite consequences do not have potential to challenge EG.**
  - Scoping calculations performed during hazard evaluation may be used to show that accident analysis is not needed.

Accident Analysis Design/Evaluation Basis Accidents

- **Accidents are DBAs when they are or were defined as part of the facility design for a new facility (or major modifications)**
  - DOE-STD-1189-2008 provides guidance for selecting and analyzing facility-level radiological and/or hazardous material release DBAs.
- **When an adequate set of DBAs does not exist, EBAs are selected from:**
  - Operational accidents –
    - process deviations (e.g., high temperature and high pressure), and
    - initiating events internal to the facility (fire, explosions, loss of power)
  - Natural events such as earthquakes, floods, tornadoes, and wildfires
  - Man-made external events such as an aircraft crash, vehicular accident, or gas pipe break

Accident Analysis DBAs/EBAs (Cont.)

- **EBAs are derived from the spectrum of hazard scenarios developed in the hazard evaluation.**
- **Two types of EBAs shall be defined for further analysis:**
  - Representative EBA (at least one bounding accident from each of the major types from the Hazard Evaluation)
  - Unique EBA (events that may be bounded by other events but have their own unique control set or other hazard/accident characteristics)

Accident Analysis DBAs/EBAs (Cont.)

- **Hazard scenarios that have the potential to challenge the EG shall be considered as candidates for DBA/EBA accident analysis except for:**

NEW

(1) Operational events that are deemed not plausible;

(2) Natural phenomena initiators of greater magnitude than those required by DOE O 420.1C; or

(3) External man-made events with a cutoff likelihood of 10^{-6}/yr, conservatively calculated.

- **EBAs may also be developed for determining the need for SS controls based on Co-located Worker consequences or MOI chemical exposures (i.e., if not quantitatively evaluated in the Hazard Evaluation)**

Accident Analysis DBAs/EBAs (Cont.)

- **An operational event is not considered plausible if it is either (not based on quantitative factors):**

  (1) A process deviation that consists of a sequence of many unlikely human actions or errors for which there is no reason or motive.

  - Considering a wide range of possible motives, short of intent to cause harm; and no such sequence of events can ever have actually happened in any nonreactor nuclear facility

  (2) A process deviation for which there is a convincing argument, given physical laws, that they are not possible.

  - The criterion cannot be used if the argument depends on any feature of the design or materials controlled by the facility's safety features or administrative controls.

Accident Analysis DBAs/EBAs (Cont.)

- Use of a lower binning likelihood threshold such as 10^{-6}/yr (i.e., BEU) for screening operational events from selection as DBA/EBAs for the accident analysis, is not appropriate.
- NEW Quantitative analysis may be used to support decisions regarding the need for SC or SS controls for operational events:
  - Completed in accordance with DOE-STD-1628-2013, including the development of a PRA plan (approved by DOE),
  - PRA results shall include an integrated assessment of accident probability and consequences of the accident event to establish the event's risk significance.
  - Key assumptions and initial conditions shall be identified and protected (Section 3.2.2).

Accident Analysis
Unmitigated Analysis

- Both Hazard Evaluation and Accident Analysis require an unmitigated analysis of consequences and likelihood
- An unmitigated consequence analysis shall be performed for plausible accident scenarios, NPH events, and external events (conservative estimate of consequences in accordance with the physical realities of the accident phenomena at a given facility, activity, or operation)
- Initial conditions and assumptions for the analysis shall be documented and evaluated to determine if controls need to be put in place to ensure the evaluation will remain valid (if assumed passive SSC prevents significant consequences, it shall be classified as either SS or SC) - see A.3 on initial conditions

Accident Analysis Unmitigated Analysis (Cont.)

- **Some additional assumptions may be necessary to define a meaningful accident scenario which could affect the magnitude of the resultant consequences**
  - Assumptions shall be protected at a level commensurate with their importance (assumption that an SSC exists does not automatically require SC or SS designation)
- **Following assumptions may be appropriate to establish a physically meaningful accident scenario:**
  - Passive safety controls not affected by the accident scenario are deemed available.
  - Passive safety controls affected by the accident scenario are deemed available based on an assessment that they will survive accident conditions.

Accident Analysis Unmitigated Analysis (Cont.)

- **Following conditions shall not be assumed to be available for unmitigated analysis of plausible accident scenarios defined in Section 3.2.1:**
  - Active safety controls, e.g., ventilation, fire suppression
  - Passive safety controls that produce a leakpath reduction in source term, such as building filtration;
- **Operator intervention actions that may abort the progression of the event**
- **ACs or safety management programs in the unmitigated analysis, e.g., combustible controls**
  - Material at risk inventory limits are an exception

Accident Analysis Unmitigated Analysis (Cont.)

- **If the unmitigated consequences of a release scenario exceed established chemical or radiological thresholds in Sections 3.3.1 and 3.3.2, SC and/or SS controls will need to be established.**
  - If the unmitigated consequences will far exceed the EG, the actual consequences need not be determined because the need for SC controls has already been identified.
  - Mitigated consequences are calculated in accordance with Section 3.2.3
    - if the application of preventive controls does not eliminate the hazard or terminate the accident scenario and prevent a release of radioactive or other hazardous materials.
- **Guidance provided for likelihood for unmitigated analysis of plausible accident scenarios defined in Section 3.2.1**

Accident Analysis
Mitigated Analysis

- **Mitigated analysis shall be performed to determine the effectiveness of SS and SC controls to protect CLW and public.**
  - Should be the same as the unmitigated analysis except that:
    - accident likelihood is estimated with preventive controls available,
    - consequences are estimated with mitigative controls available.

      Note: The term “accident” as used in this subsection also includes “hazard scenarios”
- **Where preventive controls are credited as SS or SC, the DSA shall evaluate the effectiveness of the controls to either eliminate the hazard or terminate the accident and prevent a release of radioactive or other hazardous materials.**

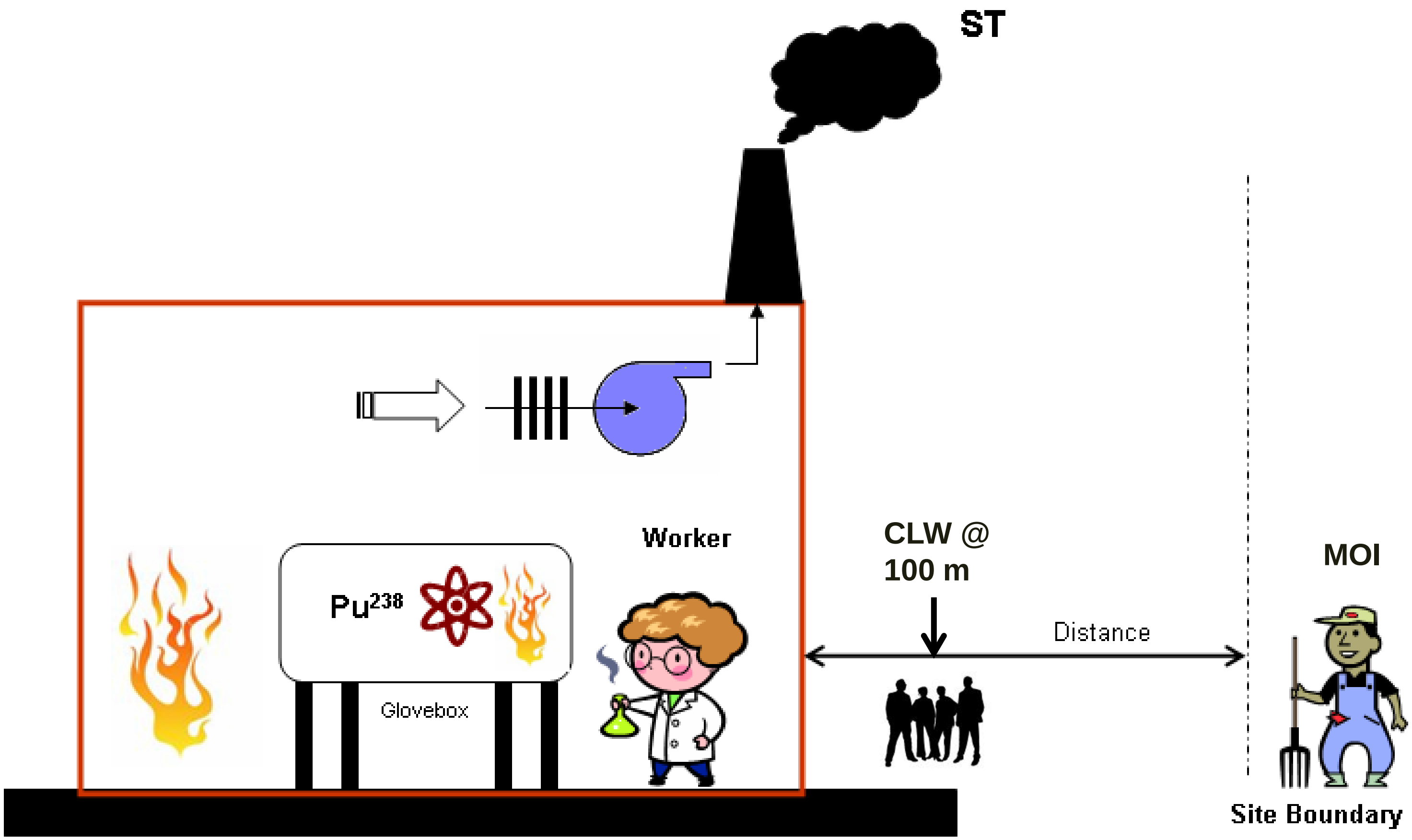
Accident Analysis Mitigated Analysis (Cont.)

- **If hazard elimination or accident termination cannot be accomplished, the effectiveness of the credited controls is evaluated in terms of the overall reduction in the likelihood of the accident.**
  - Unmitigated initiating event likelihood is combined with estimates of probabilities of subsequent events such as failure of preventive controls that have to occur to result in harm to workers or the public.
    - Appendix, Section A.4 provides examples of how to determine effectiveness of preventive controls.

Accident Analysis Mitigated Analysis (Cont.)

- **Mitigated consequence analysis is required if the credited preventive controls do not eliminate the hazard or terminate the accident.**
  - NEW This analysis shall demonstrate how SC mitigative SSC(s) and/or SACs reduce consequences below the EG and how SC (if identified) and SS mitigative SSCs and/or SACs reduce co-located worker consequences below 100 rem.
  - DOE's goal is that the combined effectiveness of the suite of credited controls (SC and SS) for a given accident is such that the event is either prevented or mitigated to reduce offsite doses well below the EG.
- **DSA Sections [3.4.3.X.5] or [3.3.2.3] document mitigated results to show the effect of hazard controls.**

Accident Analysis Consequence Calculations



Accident Analysis Consequence Calculations

- **Calculations shall be based on technically-justified input parameters and assumptions such that the overall consequence calculation is conservative.**
  - STD-3009 identifies default or bounding values that may be used without further justification.
  - STD-3009 allows use of alternative values when supported by an adequate technical basis.
  - DOE is developing an Accident Analysis Handbook, which will provide additional discussion.

Accident Analysis Consequence Calculations (Cont.)

- **An acceptable technical basis:**
  - Describes why the value selected is appropriate for the physical situation being analyzed, and
  - References relevant data, analysis, or technical standards.
  - Completeness and level of detail should increase as parameters depart from default or bounding values.

Accident Analysis
Rad. Source Term

ST = MAR x DR x ARF x RF x LPF

- ST = Source Term
- MAR = Material-At-Risk
- DR = Damage Ratio
- ARF = Airborne Release Fraction
- RF = Respirable Fraction
- LPF = Leak Path Factor

[See also DOE-HDBK-3010-94]

Accident Analysis
Material-at-Risk (MAR)

- **MAR is the bounding quantity of radioactive material that is available to be acted upon by a given physical stress from a postulated accident.**
  - MAR may be the total inventory in a facility or a portion of this inventory in one location/operation, depending on event.
  - MAR values shall be consistent with the hazard identification/evaluation, and
  - MAR values shall be bounding with respect to each accident being evaluated. [See DOE-STD-5506 for TRU waste facs.]
  - May exclude MAR in DOT Type B containers only if they survive facility accidents, but existence of such material shall be acknowledged.

Accident Analysis Damage Ratio (DR)

- **DR is the fraction of material that is actually affected by the accident-generating conditions.**
  - DOE-HDBK-3010 notes that ambiguity can result from overlapping definitions of MAR and DR.
  - NEW DR of 1.0 shall be used unless there is an applicable standard or technical basis for a different value.
    - For example, DOE-STD-5506-2007 provides specific DRs (and associated MAR guidance) for TRU waste operations.

Accident Analysis
ARF x RF

- **Airborne Release Fraction (ARF) is the fraction of the radioactive material that can be suspended in air and made available for airborne transport.**
- **Respirable Fraction (RF) is the fraction of airborne radionuclide particles that can be transported through air and inhaled into the human respiratory system.**
- **Bounding estimates from DOE-HDBK-3010 shall be used unless a different value is provided in an applicable standard or is otherwise technically justified based on physical conditions and stresses anticipated during accidents.**

Accident Analysis
Leak Path Factor (LPF)

- **LPF is the total fraction of respirable airborne material released during the accident that escapes from the building to the environment (or from glovebox, or from room, etc.).**
- **For unmitigated release calculations, LPF shall be set to unity (LPF = 1.0).**
- **For mitigated analysis, analytical tools used for LPF shall be appropriate to the physical conditions being modeled, including the use of input parameters, such that the overall LPF would be conservative.**

Accident Analysis
Rad. Dose Consequences

Dose (rem) = ST x χ/Q x DCF x BR

- **ST = Source Term**
- **X/Q = Air Dispersion Rate**
- **DCF = Dose Coefficients**
- **BR = Breathing Rate**

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

Accident Analysis Rad. Dose Consequences

- NEW **One of the following options shall be used to evaluate atmospheric dispersion and the resulting χ/Q**
  - **Option 1: NRC Reg. Guide 1.145**
  - **Option 2: DOE Toolbox Codes with default parameters**
  - **Option 3: Site/Facility specific modeling protocol**

Accident Analysis Meteorological Data

- **Key Data: Wind Speed, Wind Direction, and Atmospheric Stability**
- NEW **For the calculation of offsite doses, five years of representative, recent meteorological data shall be used as input to the model.**
  - If five years of data are not available, justification for a smaller data set shall be provided in the DSA.
- **If data not available, Pasquill stability class F and 1 m/s wind speeds may be used.**

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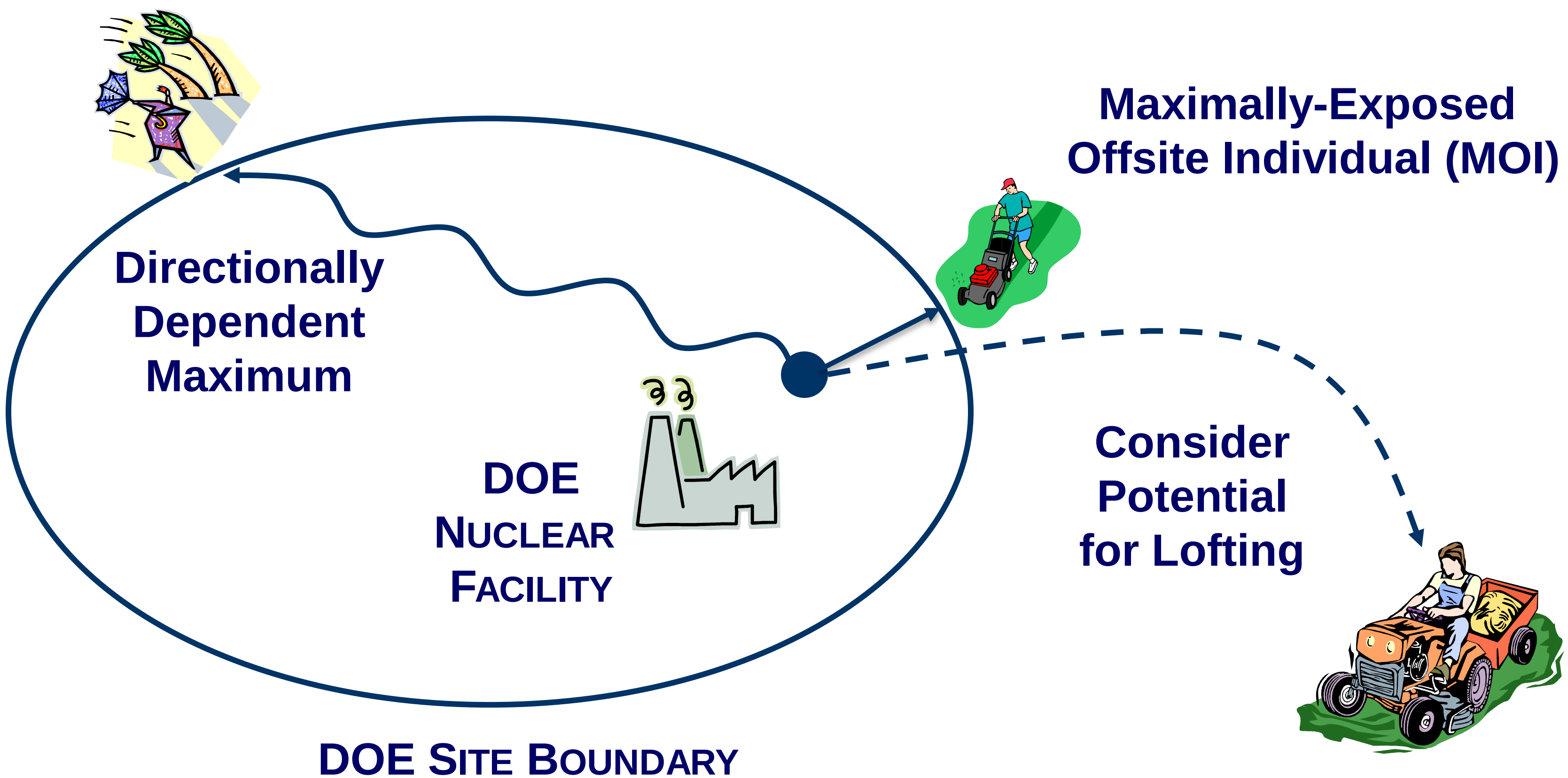
Accident Analysis Meteorological Data (Cont.)

- Option 1: Follow Reg. Guide 1.23, *Meteorological Monitoring Programs for Nuclear Power Plants*.
- Options 2 and 3: Follow Reg. Guide 1.23 or EPA-454/R-99-005, *Meteorological Monitoring Guidance for Regulatory Modeling Applications*.
- Option 3: Surface roughness may be considered.
- For accident phenomena defined by weather extremes (e.g., tornadoes or high straight-line winds), meteorological conditions associated with the accident phenomena may be used.

Accident Analysis Receptor Location



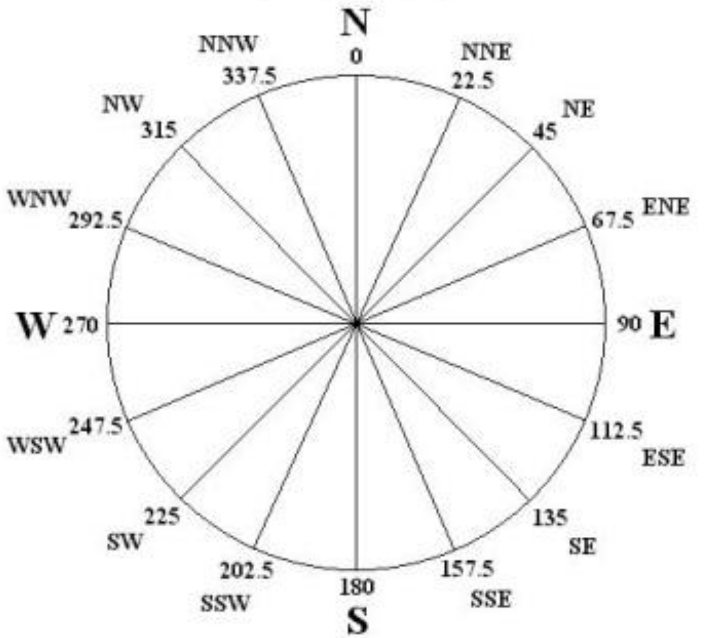
Accident Analysis Receptor Location (Cont.)

- **Comparison point shall be the location of a hypothetical MOI. This MOI is typically located at either the:**
  - Shortest distance to the DOE site boundary (directionally independent), OR
  - Site boundary location with the highest directionally-dependent dose based on a ground level release.
- **In the case of an elevated or buoyant release, the MOI could be beyond the DOE site boundary where ground level consequences are maximized.**

Accident Analysis Receptor Location (Cont.)

Directionally-Dependent Calculation:

- Consistent with Reg. Guide 1.145, Reg. Position 1.2
- Calculate for 16 compass directions
- Receptor distance at site boundary set to minimum distance within 45-degree sector centered on the compass point of interest.



Accident Analysis Release & Exposure Duration

- **<u>Option 1</u>: Regulatory Position 1.3 in Reg. Guide 1.145.**
- **<u>Options 2 and 3</u>: Exposure/release duration of 2 hours, unless otherwise established:**
  - may be extended to eight hours for slow-developing scenarios
  - may be shortened to 3 minutes (e.g., explosions and small fires).
- **Exposure period begins when plume reaches the MOI; Exposure is defined in terms of plume passage at receptor location.**
- **Accident progression should not be defined using only input variables that maximize dispersion and minimize exposure.**

Accident Analysis Offsite X/Q

- χ/Q represents the dilution of the radioactive plume via dispersion and deposition as it travels from the facility during an accident.

NEW

- While three options allow for alternative methods to calculate χ/Q values, all three options shall evaluate the dose at the MOI using either a 95th percentile for a directionally independent method OR a 99.5th percentile for a directionally dependent method.

Accident Analysis Offsite X/Q (Cont.)

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*

Accident Analysis
Offsite X/Q for Option 1

- **<u>Option 1</u>: Dispersion coefficients used within Option 1 should be consistent with Reg Guide 1.145.**
  - Reg. Guide 1.145 allows for plume meander that incorporates impacts from light winds & buildings.
  - Additional guidance on plume meander is provided in NUREG/CR-2260, *Technical Basis for Regulatory Guide 1.145.*
  - Does not consider: site characteristics, boundary layer phenomena, source depletion and transformation, and re-suspension potential

Accident Analysis
Offsite X/Q for Option 2

- **<u>Option 2</u>: DOE-approved, code-specific guidance for each toolbox code should be consulted.**
  - Many of these toolbox codes allow for setting of specific parameters within the calculations.
  - Option 2 provides a simple method for determining an appropriate χ/Q value.
- **Key Tool Box Codes: MACCS2, GENII, Hotspot, ALOHA and EPICODE (Chemical Consequences)**
  - Note: MELCOR (Leak Path Factor), CFAST (Fire Modelling) are also toolbox codes.

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

Accident Analysis
Offsite X/Q for Option 2 (Cont.)

NEW

- **Option 2**: **Use the following parameters:**
  - Non-buoyant, ground level, point source release;
  - Plume centerline concentrations;
  - Rural dispersion coefficients;
  - Deposition velocity of 0.1 cm/sec (unfiltered release of particles), 0.01 cm/sec (filtered particles), 0 cm/sec (tritium/noble gases);
  - Surface roughness of 3 cm;
  - Minimum wind speed of 1 m/s;
  - Plume meander may be used,
  - Building wake factors should not be credited in the plume dispersion, outside of those incorporated in plume meander.

Accident Analysis
Offsite X/Q for Option 3

- **<u>Option 3</u> allows the use of site-specific methods and parameters as defined in a site/facility specific modeling protocol.**
  - Should use DOE-approved tool box codes and DOE-approved methods, where possible.
  - Non-tool box codes may be acceptable if the SQA requirements of DOE O 414.1D are met.
  - Accidents with unique dispersion characteristics may be modeled using phenomenon-specific codes (e.g. fires)

Accident Analysis
Offsite X/Q for Option 3 (Cont.)

- **<u>Option 3</u>: Modeling protocol shall address the appropriateness of the model, show that the overall result is conservative, and be submitted to the DOE Safety Basis Approval Auth. for approval prior to use.**
  - For new facilities and major mods. designed per DOE-STD-1189, the modeling protocol may be included as part of a SDS (Safety Design Strategy) or other DOE-approved safety design basis doc.
  - Appendix A.7 provides contents for modeling protocol: Receptor locations, meteorological data, modeling tools, and modeling parameters.

Accident Analysis Onsite X/Q

- **Onsite X/Q of 3.5 x 10^{-3} sec/m^3 shall be used for ground-level release evaluation at the 100 meter receptor location (for co-located worker safety),**

NEW

  - When an alternate value is used, the DSA shall provide a technical basis supporting the need for the alternate value and the value selected.
  - This value may not be appropriate for certain unique situations such as operations not conducted within a physical structure.

Accident Analysis DCFs and BR

- **Dose coefficients (DCFs) consistent with International Commission on Radiological Protection (ICRP) for adults shall be used:**
  - ICRP Publication 68, *Dose Coefficients for Intakes of Radionuclides by Workers*, and
  - ICRP Publication 72, *Age-dependent Doses to Members of the Public from Intake of Radionuclides* (see also DOE-STD-1196-2011)
- **Use Breathing rate (BR) of 3.3 x 10^{-4} m^3/s (corresponds to light activity breathing rate for adults).**

Accident Analysis
Summary on Rad. Calculations

- **Calculations shall be based on technically-justified input parameters and assumptions such that the overall consequence calculation is conservative.**
  - Use default or bounding values, or else use alternative values with adequate technical basis.
- **An acceptable technical basis describes why the value selected is appropriate for the physical situation being analyzed, and references relevant data, analysis, or technical standards.**
- **Completeness and level of detail should increase as parameters depart from default or bounding values.**

Accident Analysis
Chemical Consequence Analysis

- **Quantitative evaluation of hazardous chemicals required by Section 3.1.3.3 if:**
  - not screened out during the hazard identification, and
  - with potential for consequences that exceed the SS control selection criteria in Section 3.3.2.
- **Estimate concentrations to the CLW and MOI for comparison with the Protective Action Criteria (PAC).**

Accident Analysis Chem. Consequence Analysis (Cont.)

- **Similar to the radiological consequence analysis, chemical consequence analysis should use appropriately conservative values for the parameters related to:**
  - Material release
  - Dispersal in the environment
  - Health consequences.

Accident Analysis
Chemical Source Term

- **Chemical source terms may be evaluated:**

  (1) Using DOE-HDBK-3010 if appropriate for a nonreactive chemical release phenomenon

  - Example: airborne particulates suspended from accident stress on solids or liquids or aerodynamic entrainment over time.

  (2) Or application of a DOE "Toolbox code" that may also evaluate more complex release mechanisms such as a pressurized gas release, choked-flow, or two-phase flows.

Accident Analysis Chemical Source Term (Cont.)

- **Chemical source terms may be evaluated:**

  (3) Another option is to apply 40 C.F.R. Part 68 methodology for worst-case scenario development provided in "*Risk Management Program Guidance for Offsite Consequence Analysis*" (EPA 550-B-99-009, March 2009).

  - Its Chapter 3 is generally appropriate for determining quantities and release rates for toxic gases and liquids, except where it may conflict with this Standard 3009.

- **Chemical source term calculation result applied with the chemical dispersion analysis is either a:**
  - Release rate (mass/time,) or
  - Total release quantity (mass) and specified release duration.

Accident Analysis Chemical Source Term (Cont.)

- **EPA methodology preferred; if no relevant guidance for the accident situation being modeled, DOE-HDBK-3010 defines bounding ARFs and RF mechanisms**
  - based on physical context of the accident stress (e.g., boiling liquid from a fire, shock or blast effects from an explosion, etc.).
- **DOE-HDBK-3010 also provides Airborne Release Rate (ARR) recommendations that are applicable to aerodynamic entrainment of radioactive materials as a function of time**
  - May also be applicable to chemical releases, e.g., wind suspension of powders.

Accident Analysis
Chemical Dispersion

- **Atmospheric dispersion for hazardous chemicals may be modeled similar to radiological material dispersion when applicable considering the material transport characteristics.**
- **A number of variables can influence the chemical dispersion and generation of the source term (use a DOE "Toolbox code" only when appropriate)**
  - Cryogenic/Heavy Gases –may require analysis using approved software codes designed and validated for such gases.
  - Chemical transformations that occur due to contact with air which can alter the toxicity of a plume by changing its chemical composition (e.g., uranium hexafluoride)

Accident Analysis Chemical Dispersion (Cont.)

NEW

- **If neither a radiological dispersion analysis nor a DOE "Toolbox code" is used for the chemical dispersion analysis, a modeling protocol shall address:**
  - Appropriateness of the model to the site-specific situation (including source term characterization),
  - Show that the overall result (i.e., chemical consequence) is conservative, and
  - Be submitted to the appropriate DOE Safety Basis Approval Authority for approval prior to use.

Accident Analysis Chemical Dispersion (Cont.)

- **Pasquill Stability Class F and 1 m/s wind speed may be used for chemical dispersion if representative meteorological data is not available,**
  - based on 40 C.F.R. Parts 68 and 355 recommendations from EPA for worst-case modeling assumptions and nuclear industry precedents.
- NEW **χ/Q value of 3.5 x 10^{-3} sec/m^3 may be used for ground-level release evaluation for chemical releases at the 100 meter receptor location, unless an alternate onsite χ/Q value is justified.**
  - Use of an alternate onsite χ/Q value may be considered for unique situations, such as:
    - Operations not conducted within a physical structure, or
    - Due to the chemical release and dispersion characteristics.

Accident Analysis Chemical Dispersion (Cont.)

- **When an alternate value is used, the DSA shall provide a technical basis supporting the need for the alternate value and the value selected.**

NEW

- **Section A.2 provides guidance for the calculation of exposure concentrations**
  - Dispersion and Durations
  - Time Weighted Average (TWA)
  - SCAPA Chemical Mixtures Method

Accident Analysis Summary on Chem. Calculations

- **Calculations shall be based on technically-justified input parameters and assumptions such that the overall consequence calculation is conservative.**
  - Use default or bounding values, or else use alternative values with adequate technical basis.
- **An acceptable technical basis describes why the value selected is appropriate for the physical situation being analyzed, and references relevant data, analysis, or technical standards.**
- **Completeness and level of detail should increase as parameters depart from default or bounding values.**

Accident Analysis
DSA Documentation of Results

- **DSA Section [3.4] provides expectations for Accident Analysis Summaries:**

[3.4.1]	Accident Identification Methodology
[3.4.2]	Accident Selection
[3.4.3]	Analysis of Design Basis/Evaluation Basis Accidents
[3.4.3.X]	Accident Designation
[3.4.3.X.1]	Scenario Development
[3.4.3.X.2]	Source Term Analysis
[3.4.3.X.3]	Consequence Analysis
[3.4.3.X.4]	Comparison to Consequence Thresholds
[3.4.3.X.5]	Summary of Safety Class and Safety Significant SSCs, SACs, and TSR Controls