Radiation Dispersal Device (RDD) Consequence Assessment Modeling

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Outline of this presentation

- **Overview of NARAC modeling system**
- **Recent and ongoing advances in RDD modeling:**
  1. Ballistic particle modeling
  2. Explosive cloud rise modeling
  3. Effectively communicating possible protective actions to decision makers

NARAC Modeling System Uses Several Computer Codes to Predict Consequences of Radiological/Nuclear Incidents

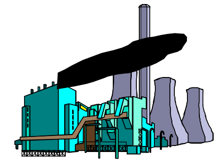
IND source models:

- LLNL *KDFOC*
- LLNL *LWAC*
- ORNL *ORIGEN*
- ORNL *DELFIC* in progress

RDD Source models:

- SNL *Source Term Calculator*
- SNL *PUFF*

Nuclear power plant sources:

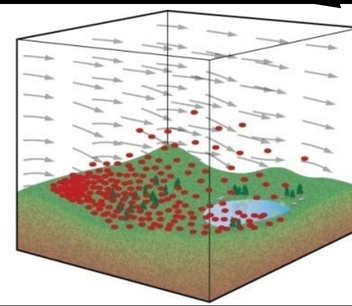


- NRC *RASCAL*

Fire source model:

- LLNL

3-D Atmospheric Dispersion and Fallout models:
LLNL *ADAPT/LODI*



DOE/LLNL's National Atmospheric Release Advisory Center (NARAC) provides 24/7 scientific/technical staff and computer systems that can produce 3-D predictions and reports for any location in the world within minutes

- **Airborne and fallout contamination and dose predictions for worker and public protection**
- **Affected population and casualty estimates**

Sandia National Laboratories

Oak Ridge National Laboratory

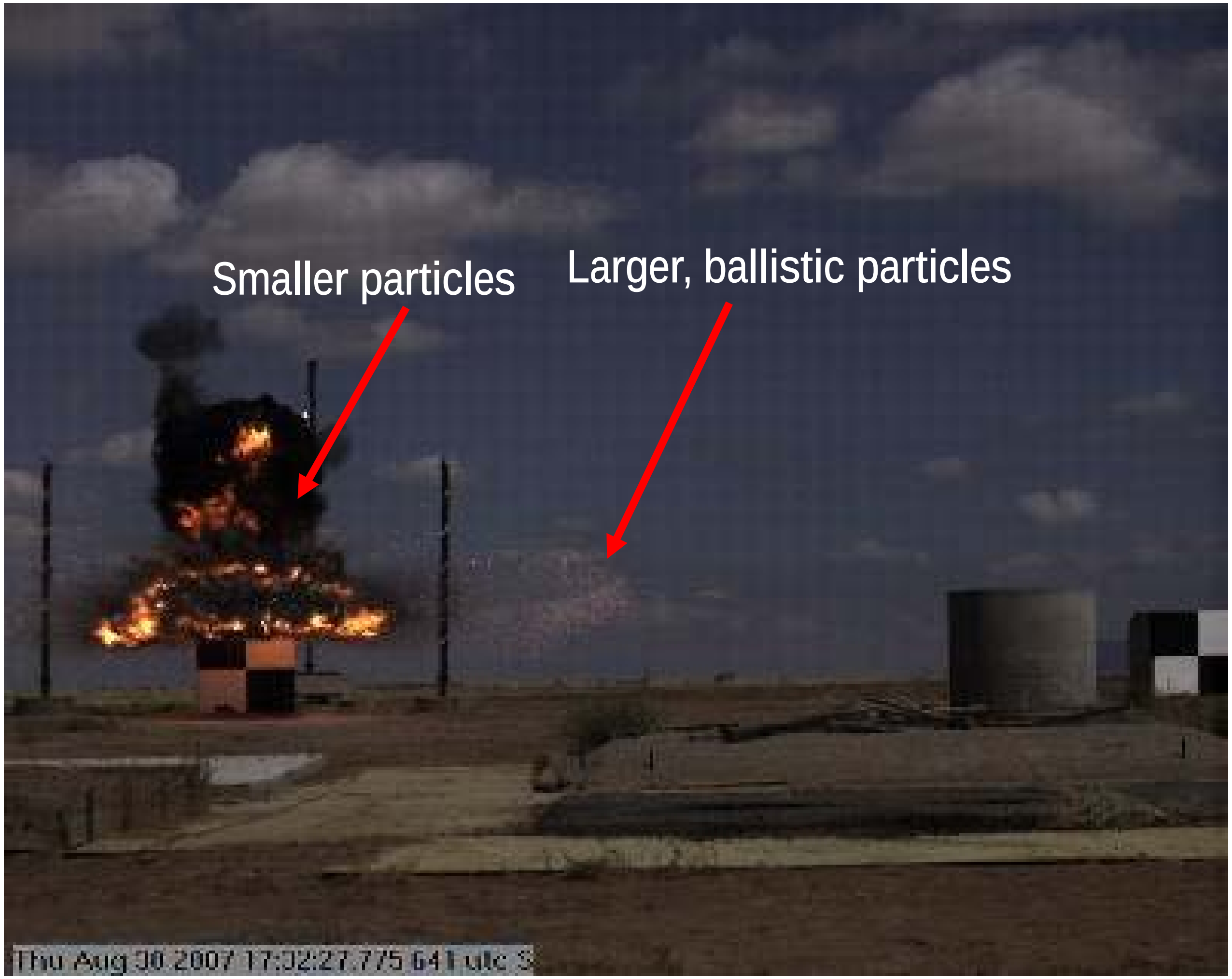
A LLNL-Sandia Project is Continuing to Improve Explosive Dispersal Models

Project goals

- More accurately simulate dispersion of particulate matter resulting from an explosion:
  - Simulation of ballistic trajectory motion of larger particles (>100 micrometer) particles that are ejected and leave the influence of the explosive, thermally buoyant cloud faster than previously assumed
  - Simulation of cloud rise for smaller amounts of high explosive mass
- Integrate new methods in operational emergency response models:
  - NARAC's *LODI* 3-D atmospheric dispersion model
  - *HotSpot* PC software

Funding Provided by DOE NNSA

Ballistic particles (>100 μm) generated by an explosion are ejected and leave the influence of the thermally buoyant cloud faster than previously assumed



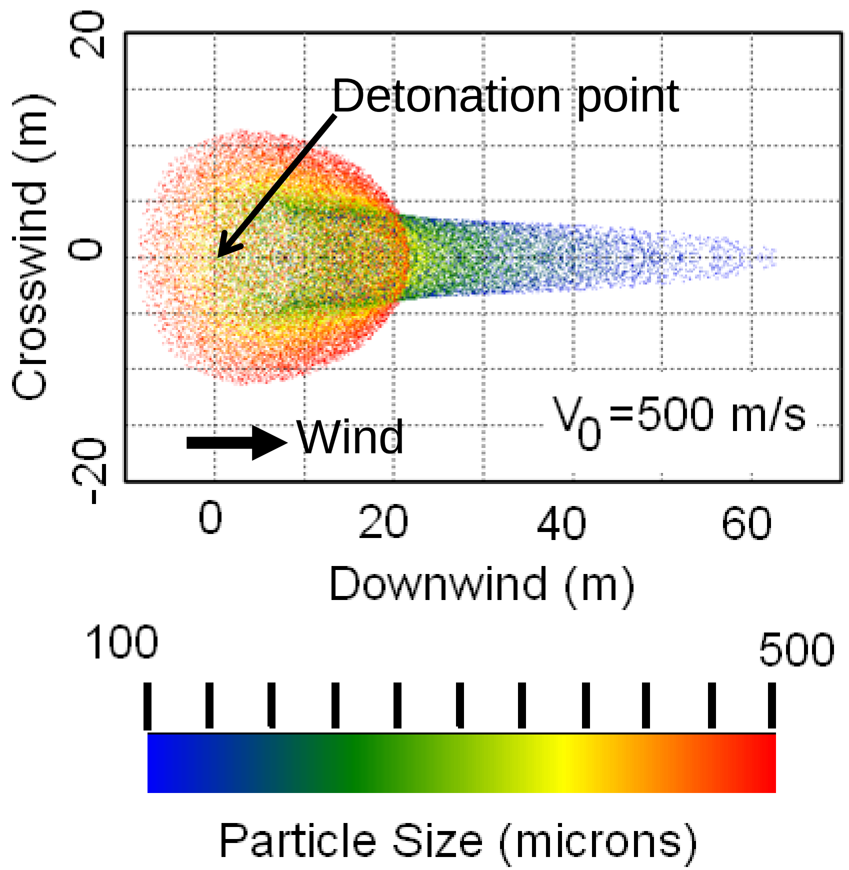
Sandia National Laboratories

Source: Dr. Fred Harper, Sandia National Laboratories

Sandia *ScatterMe* Code Calculation Results Have Been Used to Develop Ballistic Particle Deposition Parameterizations

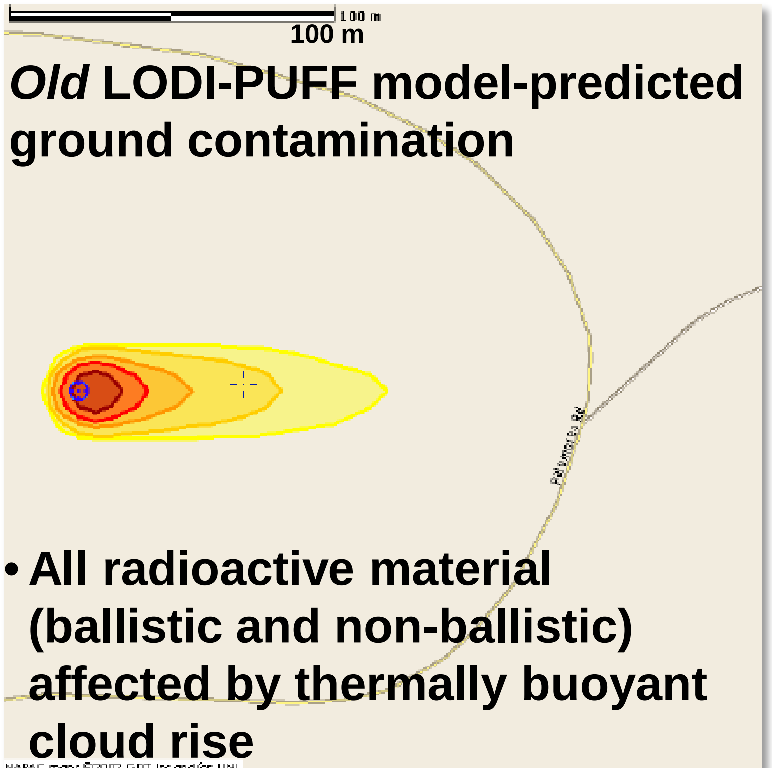
- *ScatterMe* model (developed by Dr. M. Larsen, Sandia National Laboratories)
  - Numerically solves the equations of motion to find landing spot of a ballistic particle
  - Predicts the aggregate effects of deposited ballistic particles
- Parameterizations based on *ScatterMe* are being used for NARAC's *LODI* and *HotSpot* atmospheric dispersion models

ScatterMe code predictions of Particle Deposition on Ground



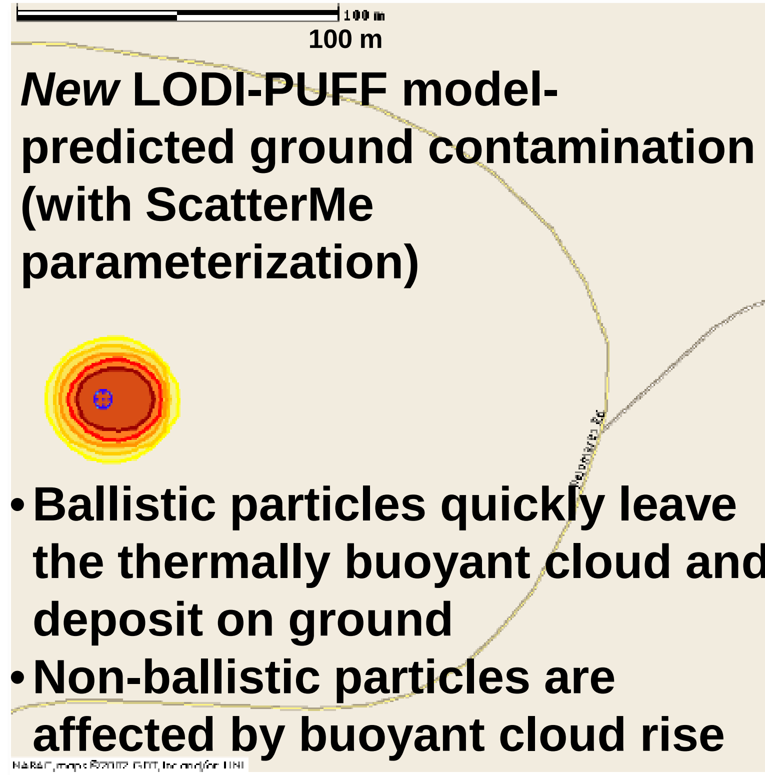
25000 particles, 100-500 micron aero, Wind=3 m/s Density = 4.0 gm/cc

New ballistic particle modeling methods produce significantly different predictions of ground deposition and ground shine dose



Old **LODI-PUFF model-predicted ground contamination**

- **All radioactive material (ballistic and non-ballistic) affected by thermally buoyant cloud rise**



New **LODI-PUFF model-predicted ground contamination (with ScatterMe parameterization)**

- **Ballistic particles quickly leave the thermally buoyant cloud and deposit on ground**
- **Non-ballistic particles are affected by buoyant cloud rise**

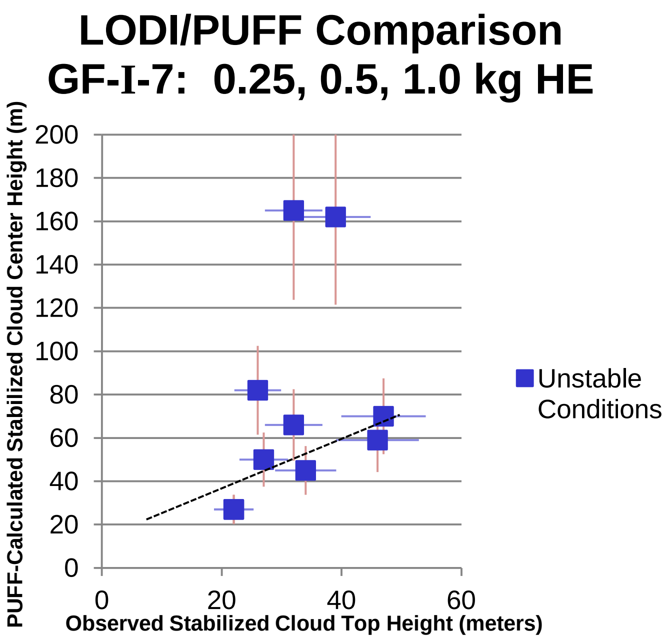
Percent of activity versus particle size assumed in this example (depends on material/design of explosive device):

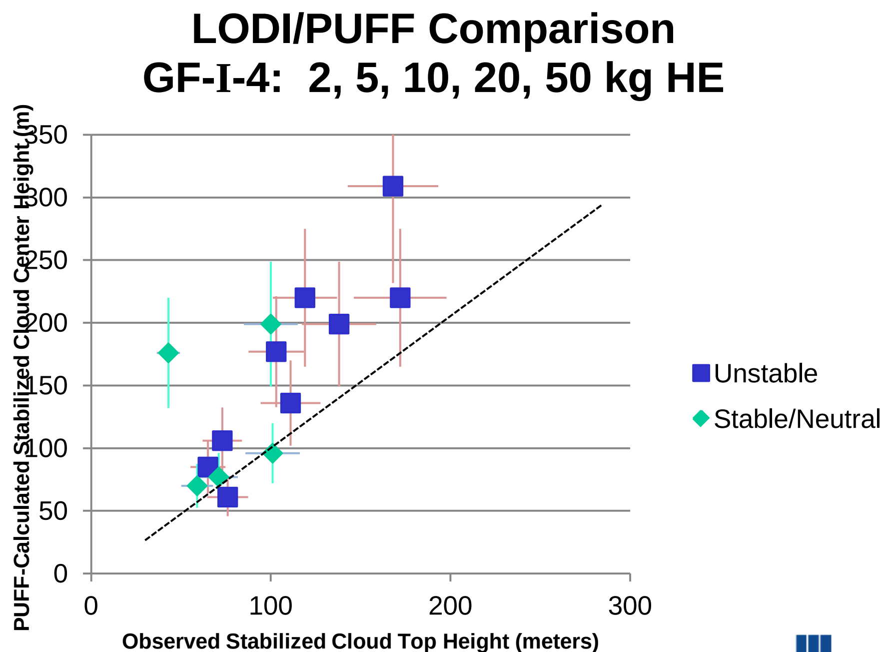
30%	0.1-100 micrometers
70%	100-1000 micrometers

Model validation versus field experiment data is ongoing

PUFF Model Predicted Cloud Top Height Typically are Too High for Lower HE Amounts

- Data from two series of Green Field experiments (GF-I-4 and GF-I-7) were used to compare NARAC LODI/PUFF cloud-rise calculations to observed cloud rise. The experiments involved detonations of 0.25 to 50 kg of explosives under unstable, neutral, and stable atmospheric conditions.
- The results show that LODI/PUFF tends to over-predict thermally-stabilized cloud heights, compared to the GF observations

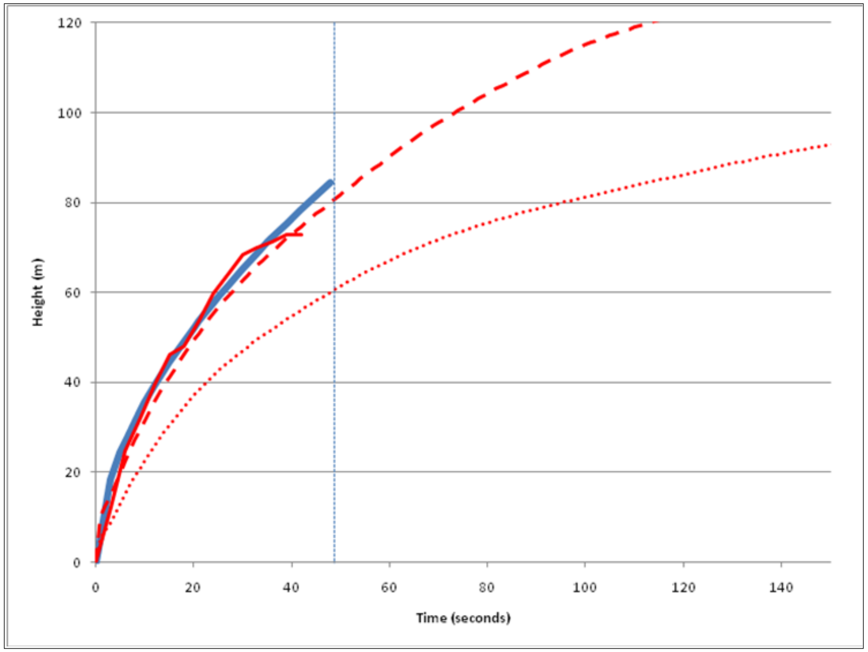




PUFF Model Accurately Predicts Rate of Cloud Rise

- The PUFF-calculated cloud top and cloud center heights typically continue increasing beyond the Green Field (GF) experiment-based cloud-rise parameterization time limit, t_{max} (48 seconds in this case).
- Final PUFF-predicted height at t_{max} matches the observed maximum height quite well

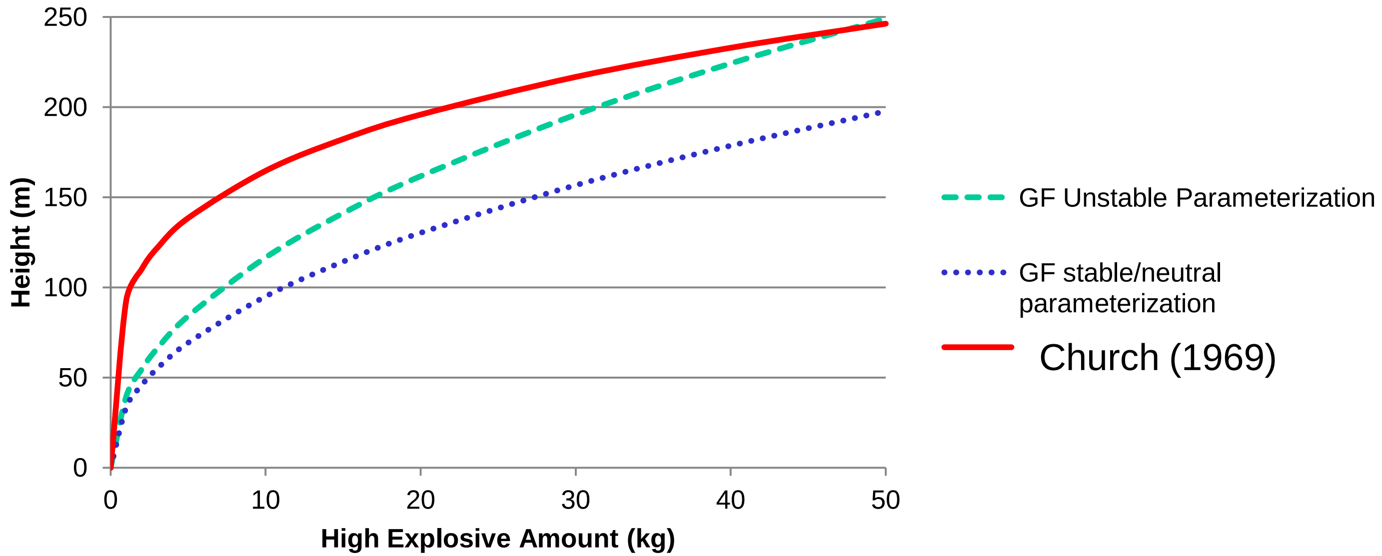
5kg Explosion Cloud Top (and Center) Height vs. Time



Solid blue line: GF parameterization for unstable
Solid red line: 5kg observed cloud top
Dotted red line: 5kg PUFF cloud center
Dashed red line: 5kg PUFF cloud top
Vertical dashed blue line: GF parameterization t_{max}

Simpler Church (1969) Parameterization Used in HotSpot code Under-predicts Green Field Experiment Cloud Heights for High Explosive Amounts Less than 50 kg

- The HotSpot model currently uses the formula developed by Church (1969)*, which is atmospheric stability independent): $H=76w^{0.25}$, where H is height in meters, and amount of high-explosive in pounds of TNT-equivalent is w.
- Two (unstable and stable/neutral conditions) Greenfield (GF) cloud height parameterizations are based on Israel experiment data.
- GF parameterizations predict a lower stabilized cloud top for all atmospheric stability conditions for high-explosive amounts less than 50 kg.

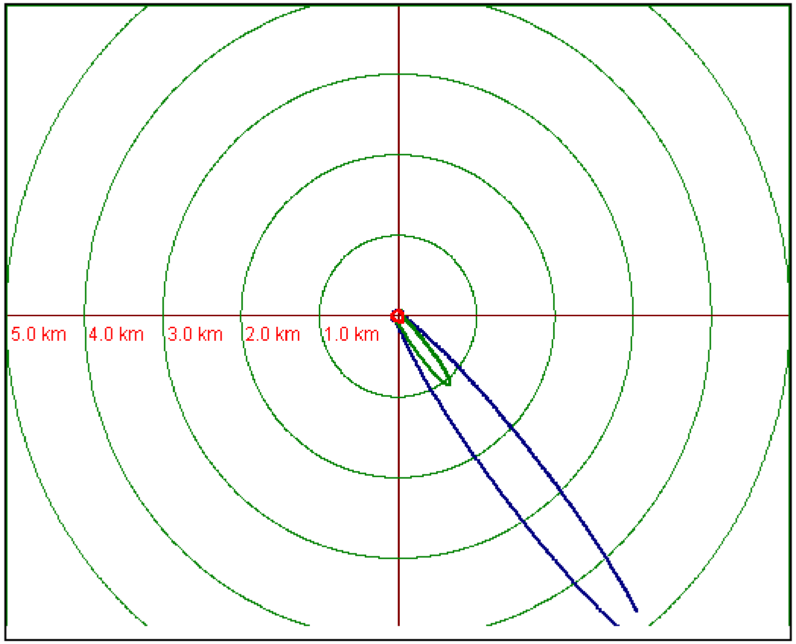


***Church, H. W. (June, 1969). *Cloud Rise from High-Explosives Detonations*, Sandia Laboratories, TID-4500, p. 14 (53rd ed., UC-41, Health and Safety, SC-RR-68-903).**

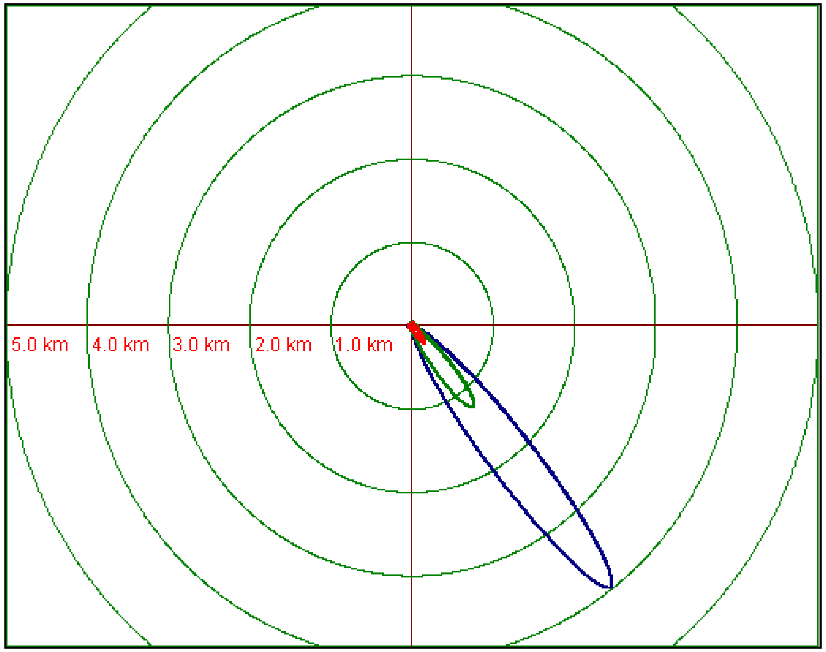
Using New Green Field Cloud Top Parameterization Significantly Changes HotSpot-Predicted Deposition

- HotSpot results show noticeable differences in calculated surface concentrations due to lower GF cloud tops vs. those predicted by current algorithm.
- The deposition contours below show comparisons between the original HotSpot (Church, 1969) and HotSpot with GF-predicted stabilized cloud top for GF shot c5 (50 kg HE).

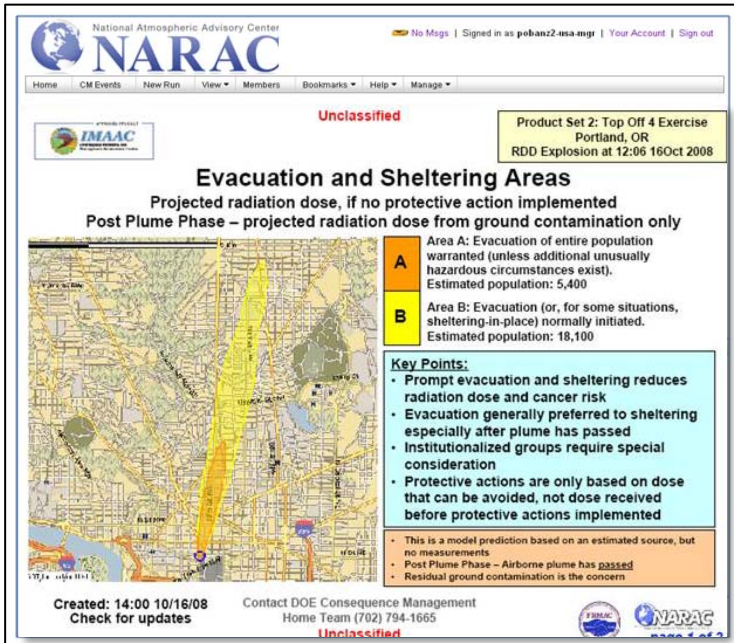
HotSpot Large-particle Deposition: Church cloud height



HotSpot Large-particle Deposition: GF cloud height



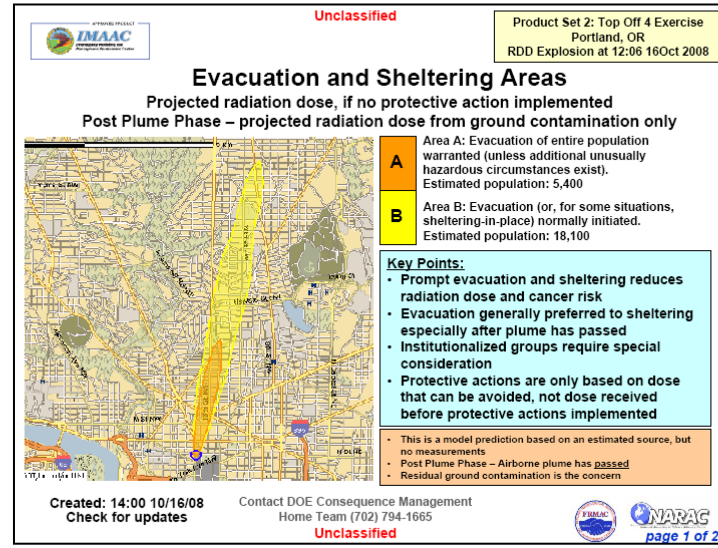
NARAC/IMAAC Products are Distributed Through the Web to Guide Response Decisions on Evacuation, Sheltering, Relocation and Protection of the Public and Workers

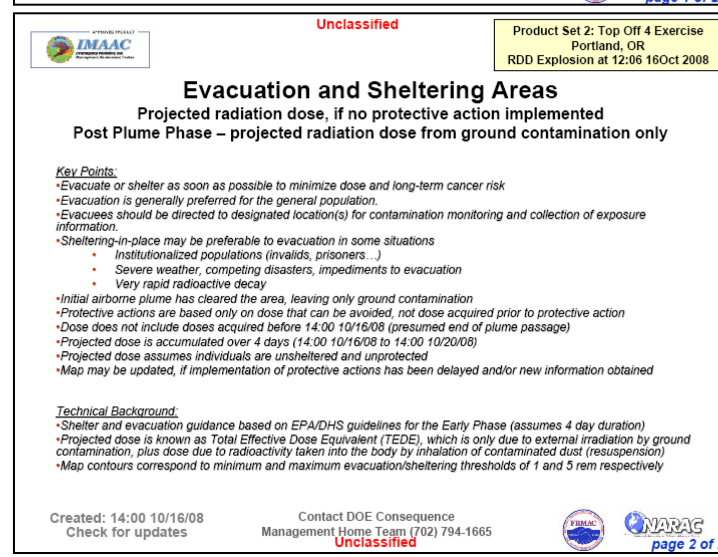


NARAC/IMAAC supports over 300 collaborating local, state, and federal agencies, 2,500 on-line users, and 10,000 requests per year, including approximately 100 exercises and 20 real-world events annually requiring staff support.

New Briefing Versions of NARAC/IMAAC Products Are Being Deployed

- DOE and DHS supported the development and interagency review of “Briefing Product” versions of NARAC/IMAAC and FRMAC products
- Products intended to help subject matter experts brief decision-making officials
- Explain possible actions, like sheltering and evacuation, that need to be considered and why
- Communicate protective action guides in plain, non-technical language
- NARAC software quickly produces PowerPoint versions of briefing products



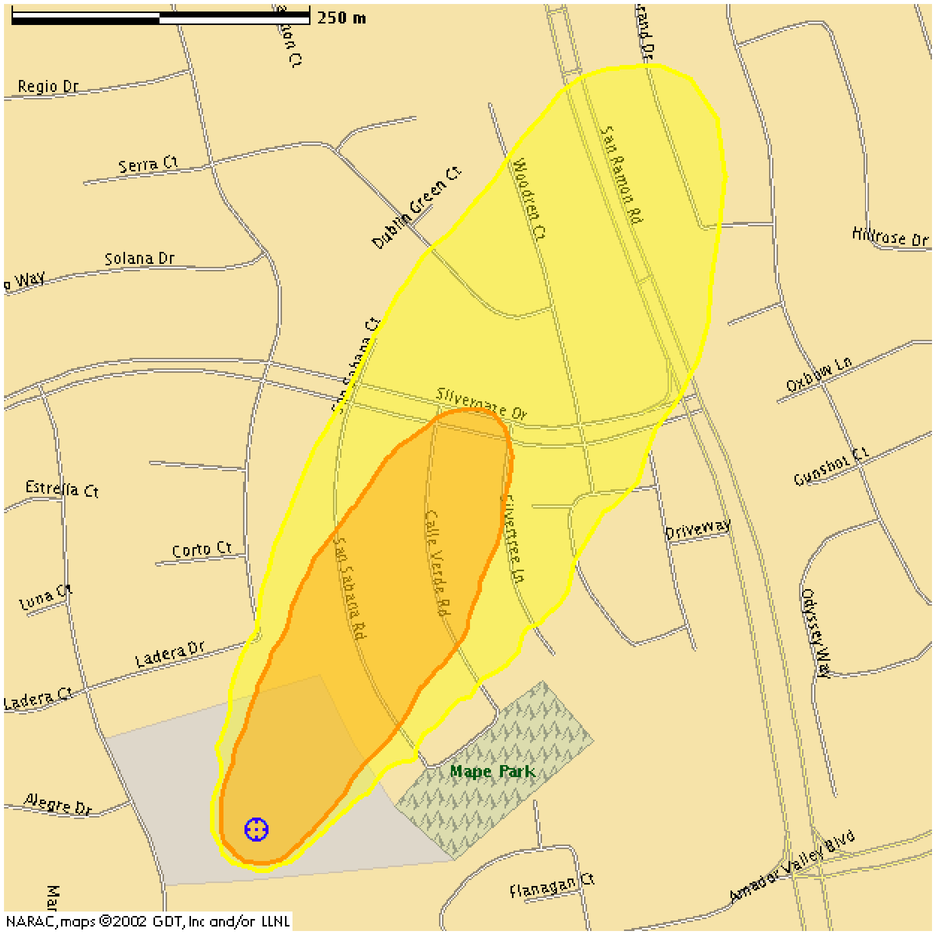


Example RDD Briefing Product Slide 1

Automated Report: Testing
Livermore Lab, ca
RDD Explosion at 09 Sep 2009 18:00 UTC

Predicted Evacuation and Sheltering Areas Based on EPA/DHS Guides

Applicable within first hours/days while radioactive cloud is present



A	**Evacuation of entire population warranted, unless additional unusually hazardous circumstances exist (exceeds 5 rem). Estimated Population: 80**
B	**Evacuation or sheltering normally initiated (1 to 5 rem). Estimated Population: 250**

Notes:
- **Promptness of evacuation and/or sheltering reduces radiation dose and cancer risk.**
- **Sheltering-in-place can be more protective than evacuation while radioactive cloud is present.**
- **Radiation dose predicted for maximally exposed individuals and includes both dose from contaminated air, plus dose from ground contamination over four days.**
- **Protective actions are only based on dose that can be avoided. Prediction does not include dose received before 9 Sep 2009 19:00 UTC.**

Assumptions:
- **Areas shown are model predictions based on an estimated source term but no measurements.**
- **Plume Phase - Radioactive cloud may still be present or imminent.**
- **Four days exposure to both airborne and ground contamination.**

Briefing Product for Public Officials
Current: 30 Sep 2009 14:51 UTC
Check for updates

Example RDD Briefing Product Slide 2

Predicted Evacuation and Sheltering Areas Based on EPA/DHS Guides

Applicable within first hours/days while radioactive cloud is present

Key Points

- **Protective actions are based on dose that can be avoided.**
- **Areas shown do not include dose received before 9 Sep 2009 19:00 UTC.**
- **Greatest hazard is due to exposure to the radioactive cloud. Evacuation before radioactive cloud is present is best, but avoid evacuation in the radioactive cloud.**
- **Radioactive cloud is expected to clear the contoured areas by 9 Sep 2009 20:45 UTC.**
- **Sheltering-in-place may be preferable to evacuation in some situations**
  - **If radioactive cloud is present or its arrival is imminent,**
  - **For certain populations needing special consideration (hospitals/nursing homes, prisoners, elderly...),**
  - **Other hazards are present which complicate or impede evacuation (severe weather, competing disasters...).**
- **Sheltering followed by delayed evacuation may be best if radioactive decay is very rapid.**
- **Predicted dose is accumulated over 4 days (9 Sep 2009 19:00 UTC to 13 Sep 2009 19:00 UTC).**
- **Predicted dose assumes individuals are unsheltered and unprotected.**
- **Use the "Radioactive Cloud has Passed" map after radioactive cloud passes.**

Predicted Evacuation and Sheltering Areas Based on EPA/DHS Guides

Applicable within first hours/days while radioactive cloud is present

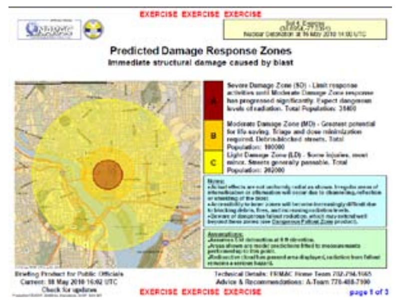
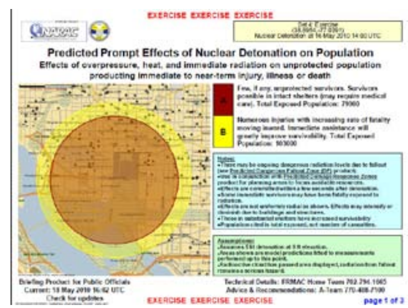
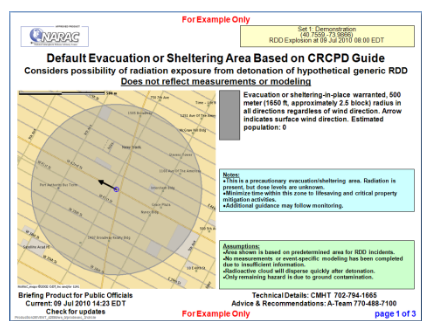
Presenter Notes - Additional Information

- PAG - Protective Action Guideline, projected dose at which a specific protective action to reduce or avoid that dose is warranted.
- Protective actions are based only on dose that can be avoided, not dose acquired prior to implementation of the protective action.
- Areas shown do not include dose received before 9 Sep 2009 19:00 UTC.
- Areas shown are model predictions based on an estimated source term but no measurements.
- Reduce radiation exposure to minimize long-term cancer risk. Evacuation and sheltering reduce radiation exposure.
- Exposure to the radioactive cloud presents the greatest hazard, because dose results from radiation by the cloud, inhalation of radioactivity, plus radiation from contamination on the ground.
- Completion of evacuation before plume arrival is best. Evacuation in radioactive cloud may result in more dose than sheltering until it passes. Evacuees in cloud should cover mouth & nose with available filter materials.
- Evacuation and shelter guidance based on EPA/DHS Early Phase guidelines
  - "Evacuation (or, for some situations, sheltering) should normally be initiated at 1 rem."
  - "Sheltering may be the preferred protective action when it will provide protection equal to or greater than evacuation, based on consideration of factors such as source term characteristics, and temporal or other site-specific conditions."
  - "Because of the higher risk associated with evacuation of some special groups in the population (e.g. those who are not readily mobile), sheltering may be the preferred alternative for such groups as a protective action at projected doses up to 5 rem."
  - "Under unusually hazardous environmental conditions use of sheltering at projected doses up to 5 rem to the general population (and up to 10 rem to special groups) may become justified."
- Sheltering followed by delayed evacuation may be best if radioactive decay is very rapid (e.g. radioiodine or nuclear detonation).
- Radioactive cloud expected to clear contoured area by 11 Sep 2009 02:45 UTC.
- A different map, based only on the radioactivity deposited and excluding the radioactive cloud, must be used after the radioactive cloud has passed.

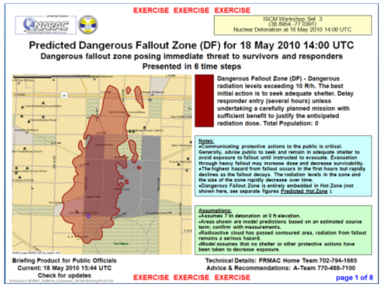
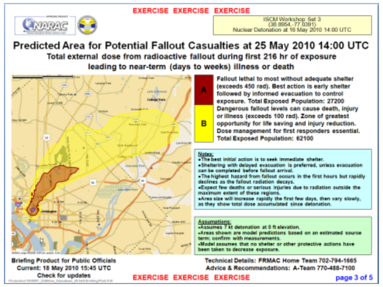
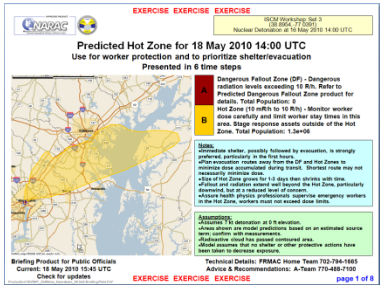
Presenter Notes - Technical Background

- Guidance based on EPA and DHS PAGs, as given in:
  - "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents", (EPA 400-R-92-001, May 1992).
  - "Protective Action Guides for Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents", (Federal Register, Vol. 71, No. 1, Jan. 3, 2006, pg 174).
- "The PAG for evacuation (or, as an alternative in certain cases, sheltering) is expressed in terms of the projected sum of the effective dose equivalent from external radiation and the committed effective dose equivalent incurred from inhalation of radioactive materials from exposure and intake during the early phase."
- Predicted dose is known as Total Effective Dose Equivalent (TEDE) and includes the following:
  - External irradiation by the radioactive cloud plus inhalation of the contaminated air as it passes,
  - Also includes external irradiation by ground contamination, plus dose due to radioactivity taken into the body by inhalation of contaminated dust (resuspension).
- Predicted dose is accumulated over 4 days (9 Sep 2009 19:00 UTC to 13Sep 2009 19:00 UTC).
- Predicted dose assumes maximum possible exposures, but only considers dose that can be avoided by protective actions. Doses received prior to this point in time are not considered.
- Radioactive contamination is expected outside the contoured areas, but not at levels expected to exceed federal guidelines for evacuation and sheltering based on current information.
- Additional technical and background information is provided in the Consequence Report containing the detailed, technical version of this calculation.
- Briefing Products are intended for presenting a common operating picture to key leaders and decision makers. Other more technical products are available (Standard Products).
- Contact the FRPCC Subcommittee for Environment, Food and Health (Advisory Team) for advice and recommendations. Available by calling the CDC Emergency Operations Center (EOC) at 770-488-7100.

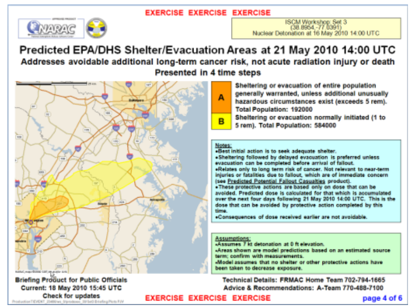
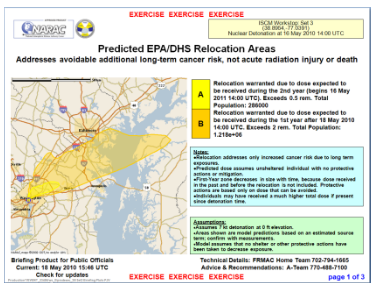
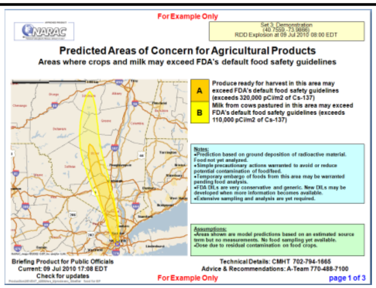
Types of Briefing Products:
Prompt Effects

Time Phase	Product		Purpose
Early (minutes to hours)	Predicted Damage Response Zones (IND)		• Estimate immediate structural damage and blocked street • Inform search & rescue
	Prompt Effects on Population (IND)		• Estimate immediate near-term injury, illness or death • Estimate areas with immediate injuries and fatalities • Prioritize rescue
	Default Evacuation or Sheltering Area (RDD)		• Guide precautionary sheltering and evacuation decision • Guide access control and monitoring

Types of Briefing Products:
Ground Deposition/Fallout Dose

Time Phase	Product		Purpose
Early (hours to days)	Predicted Dangerous Fallout Zone (IND)		• Estimate high dose fallout zone posing immediate fatality threat to survivors and responders • Presented for multiple times, as fallout rapidly decays • >10 R/h
	Predicted Area for Potential Fallout Casualties (IND)		• Estimate total fallout casualties/ injuries • Estimate total external dose from radioactive fallout during first hours to days of exposure leading to near-term (days to weeks) illness (100 rad) or death (450 rad) • Presented for multiple times, as fallout rapidly decays
	Predicted Hot Zone /Worker Protection Areas (IND/RDD)		• Use for worker protection and stay time guidance • Determine access control area • Presented for multiple times, as fallout rapidly decays • > 10 mR/hr

Types of Briefing Products:
Plume and Fallout Dose

Time Phase	Product		Purpose
Early (hours to days)	Predicted EPA/DHS Sheltering/ Evacuation Areas (RDD, IND) (NPP in development)		• Guide sheltering and evacuation decisions • Assess avoidable additional long-term cancer risk, not acute radiation injury or death (1-5 Rem, >5 Rem in 4 days) • Presented in multiple times
Intermediate (days to months) and Late Phases (months to years)	Predicted EPA/DHS Relocation Areas (RDD, IND) (NPP in development)		• Guide population relocation decisions • Assess avoidable additional long-term cancer risk, not acute radiation injury or death (2 Rem in first year, 0.5 Rem in subsequent or later year)
	Predicted Areas of Concern for Agricultural Products (RDD, IND) (NPP in development)		• Guide crop sampling • Guide crop/food control decisions • Predict areas where crops and milk may exceed FDA's food safety guidelines based on fallout

Ongoing and Future Work Needed

Model Improvement:

- Modeling the effect of entrained surface material (e.g., soil) on particle size, cloud rise and dispersion
- Improved cloud-particle coupling that account for internal circulation in cloud
- Model validation using concentration/deposition measurements

Operational Tools:

- Real-time model refinement using measurements – more quickly run multiple model simulations and refine predictions using initial deposition measurements
- Comprehensive spatial databases and tools for predicting indoor exposure from RDDs, including building infiltration of airborne radioactive contamination
- Provide real-time information on arrival and departure times for airborne contamination, to help make decision on when sheltering-in-place (or evacuation) should begin, and when it should end
- Determining and communicating sheltering and evacuation-routing options to decision makers