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Radiological Dispersal and Prediction Models

Heather M. Pennington

Nuclear Incident Response Programs, 06631

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Contributions by: Fred Harper and Heather Pennington
Sandia National Laboratories
John Nasstrom and Brenda Pobanz
Lawrence Livermore National Laboratory

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Discussion

- Time Scales for Explosive Aerosolization
- Discussion of Parameters that Matter in Plume Dispersal
- Comparison of DOE Dispersal Models
- Overview of Dispersion Models HotSpot and NARAC
- In-depth Look at the SHARC Model
- Mitigation Methods
- Turbo FRMAC Overview
- Briefing Products

Time Scales for Explosive Aerosolization/Fragmentation Phenomenology

µs

ms

< s

- Microseconds (µs)
  - Shock wave interaction with material
    - Shock melting/vaporization
    - Shock Sintering
    - Failure in tension (strain rate, shear band melt)
  - Initial particle size distribution
- Milliseconds (ms)
  - Fireball dynamics
    - Fireball/surface interaction
    - Ballistic release of some particles/frag
    - Agglomeration/Combustion
  - Final particle size distribution
- Milliseconds to seconds
  - Plume rise
- Seconds to minutes
  - Late dispersal flow downwind

Computational Fluid Dynamics Codes & Dispersal Models

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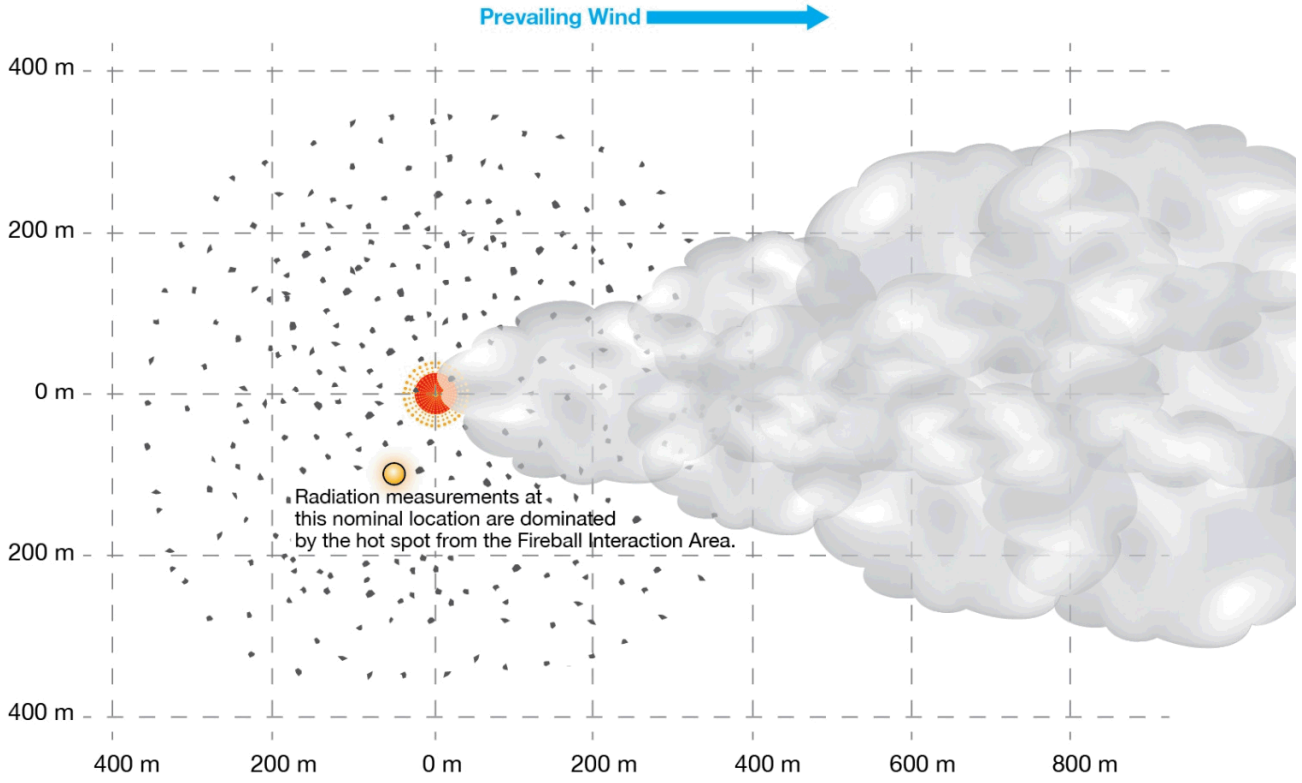
- Computational Fluid Dynamics Codes: AUTODYN and CTH
  - Energy deposition, initial particle size distribution
  - Examples are:
    - Eulerian (Finite Volume, finite difference schemes)
    - Lagrangian (Finite Element Schemes)

- Dispersal Models: HotSpot, SHARC[1] and NARAC[2]
  - Fireball dynamics; early dispersal
  - Plume rise
  - Late dispersal

1. Specialized Hazard Assessment Response Capability
2. National Atmospheric Release Advisory Center

Particle/Frag size, HE Amount/Location Determine Deposition Pattern – Size Matters

- Fireball Interaction Area
- Large Particles (~ 100-500 µm)
- Ballistic Fragments (> 1 cm)
- Downwind Fallout (small particles)



Basis for all of this

More than 1,000 RDD characterization tests have been performed at SNL in the last 25 years

Have semi-empirical models for metals in different geometries, liquids, salts, ceramic powders, and preliminary models for ceramics.

Size of particulate released depends on device geometry material physical and chemical properties

MATERIAL	PHYSICAL FORM	DEVICE STRATEGIES TESTED
Ag	Metal	17
Al	Metal	5
Bi	Metal	3
Co	Metal	1
Cu	Metal	2
Mo	Metal	1
Pb	Metal	1
Ir	Metal	3
Stainless Steel	Metal	2
Ta	Metal	1
U	Metal	1
CeO2	Ceramic (2 densities per device)	7
$SrTiO_3$	Ceramic (3 densities per device)	8
Tb/Pd	Cermet	1
Various Materials	Liquid	8
BaSO4	Slurry	1
CeO2	Ceramic Powder	7
MnO2	Ceramic Powder	4
UO2	Ceramic Powder	1
CeO2	Pressed Powder	3
CsCl	Powdered Salt	7
BaSO4	Powdered Salt	2

DOE Dispersal Modeling Tools

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The capabilities of different modeling tools – *HotSpot*, Specialized Hazard Assessment Response Capability (*SHARC),* and *NARAC* have different, complementary capabilities:

- **HotSpot's** strengths are minimal input data requirements, very fast computations, and portability to run on computers at multiple locations.
- **SHARC's** strengths are moderate input data requirements, vertical variation in meteorological conditions, fast computations for running a range of possible scenarios, population database and ability to run in a wide variety of locations and on different computer systems including a variety of different classified systems.
- **NARAC's** strengths are 3-D time-varying weather conditions, complex terrain effects, the ability to predict longer distance and longer time impacts, population database, and the ability to update predictions using environmental measurement data.

Comparison of Modeling Software Tools Capabilities

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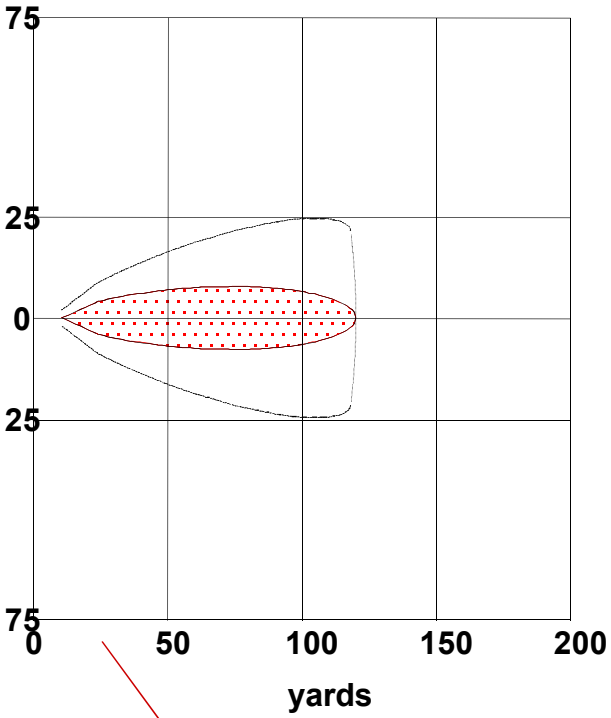
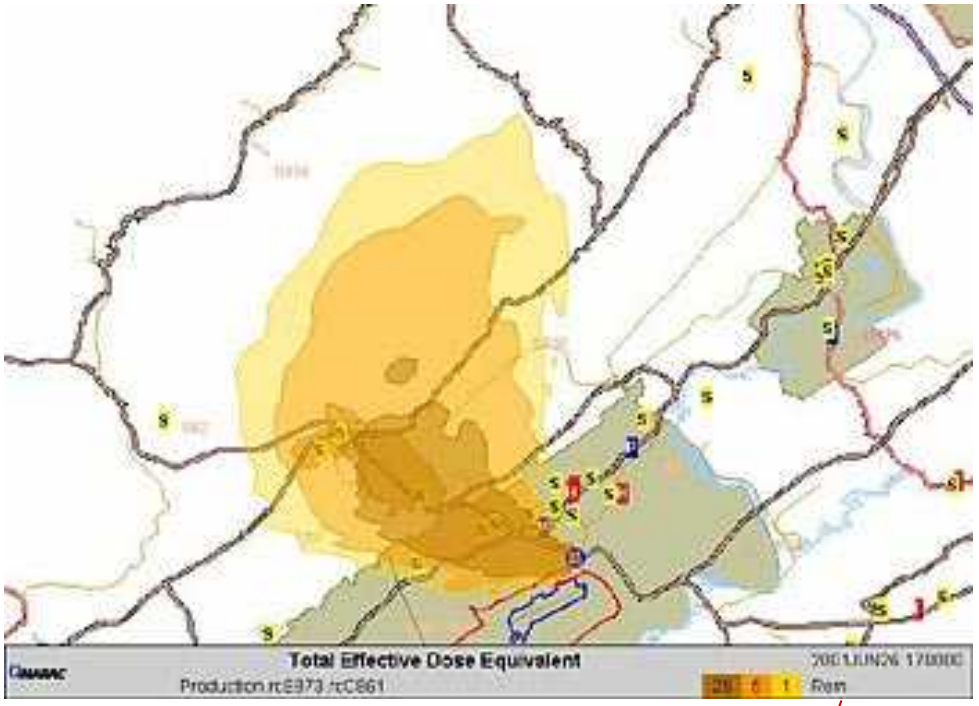
Model	HotSpot	SHARC	NARAC
Scenarios	• Nuclear detonation • Radiation dispersal device • Weapon accident explosion • General radiological release • Weapon accident fire • Facility fire • Stack venting	• Nuclear detonation • Radiation dispersal device • Weapon accident explosion • General radiological release	• Nuclear detonation • Radiation dispersal device • Weapon accident explosion • General radiological release • Weapon accident fire • Facility fire • Stack venting • Nuclear power plant accident
Meteorological data	• Single point • No time variation	• 1-D (vertical) • No time variation	• 3-D • Time-varying
Terrain	Flat	Flat	Complex terrain
Average run time	1 min	5 min	10-30 min
Population Database	• No database available	• LandScan • U.S. Census	• LandScan • U.S. Census
Products	• Prompt effects • Fallout pattern and casualties • Worker protection guides • Sheltering/evacuation guides	• Prompt effects • Fallout pattern and casualties • Worker protection guides • Sheltering/evacuation guides • Electromagnetic pulse (EMP) effects • Shipping route options • Containment and mitigation effects	• Prompt effects • Fallout pattern and casualties • Worker protection guides • Sheltering/evacuation guides • Relocation guides • Food/crop intervention guides • Nuclide-specific fallout contamination levels with fractionation • Monitoring mission planning
Information	https://narac.llnl.gov/HotSpot/HotSpot.html	http://nirp-irn.sandia.gov/	https://narac.llnl.gov

Differing Levels of Complexity





Simple Model

Sophisticated Model

HotSpot

(Developed by Steven Homann, Lawrence Livermore National Laboratory)

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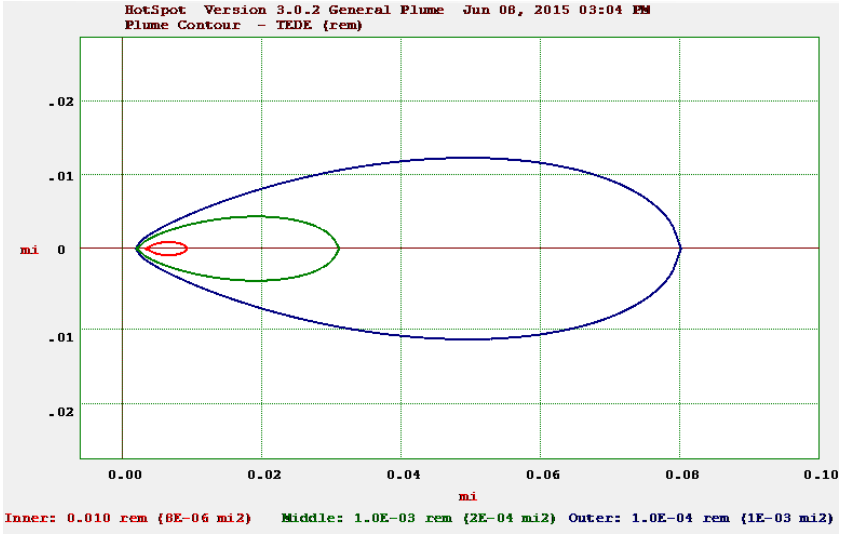
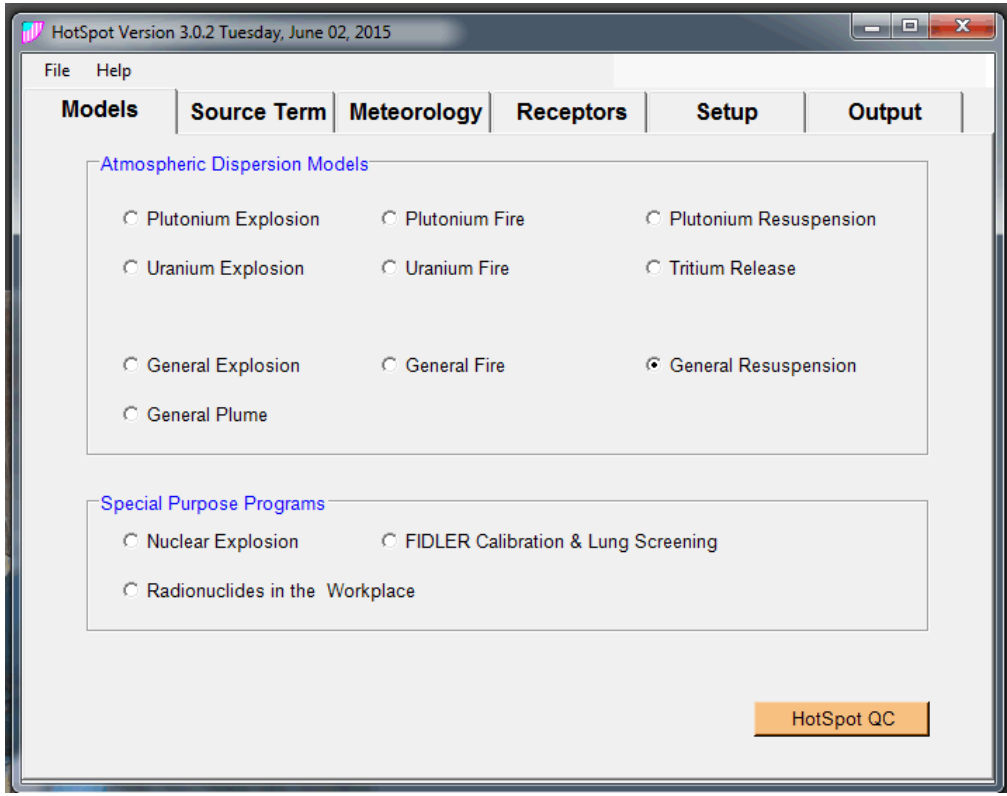
Simple Model

- Gaussian plume deposition
- Fast (results in a few minutes)
- Portable
- Easy to use





NARAC Provides Operational Services, Tools, and Expertise for Preparedness, Response and Recovery

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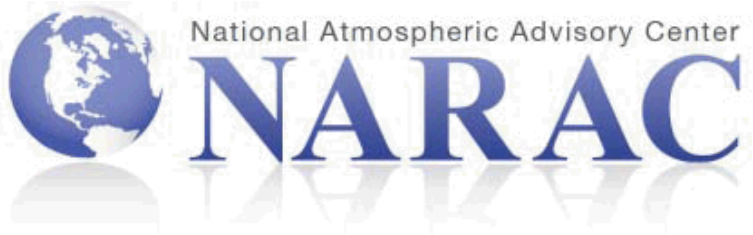
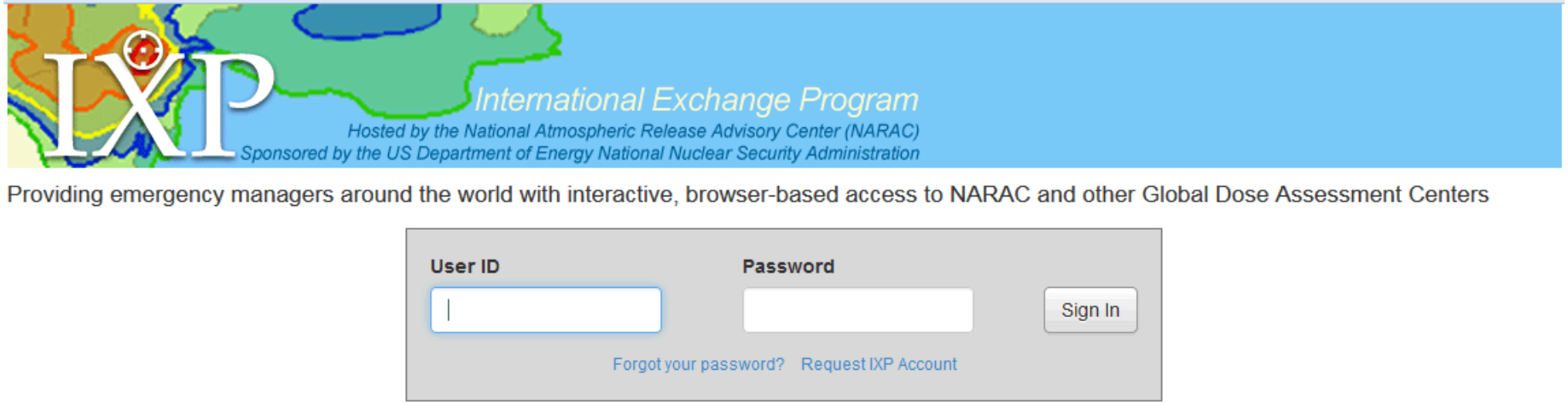
- Event Information
  - Weather data
  - Nuclear, radiological source information
  - Terrain, land uses and population databases
  - Measurement data and observations
- Operational Services and Expertise
  - 24/7/365 expert scientific staff
  - Detailed analysis, expert interpretation, quality assurance and training
  - Event reconstruction
- Actionable Information
  - Hazard areas and affected populations
  - Health effect, public protective actions and worker protection levels based on federal guidelines
  - Casualty, fatality and damage estimates
  - Planning and consequence assessments



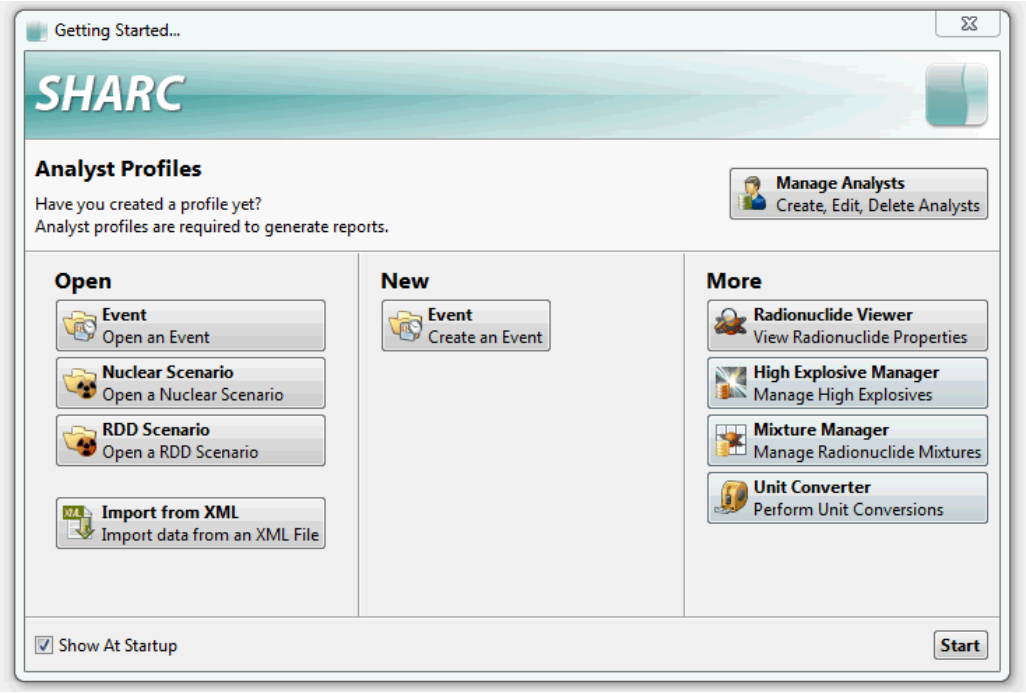
NARAC International Exchange Program

- The IXP is available to all members states of the IAEA
- Accounts can be requested by going to the IXP site and clicking “Request IXP Account”
- https://ixp.llnl.gov



SNL Modeling Tool Set: SHARC[1]

- Two scenarios available
  - Nuclear Scenario
  - RDD Scenario
    - Buoyant (explosively driven)
    - Non-buoyant
- Automated calculation of fatality and casualty estimates using population databases
  - Landscan / U.S. Census
- Integrated with the FRMAC[2] health physics assessments
- Automated briefing products and report generation
- Designed to provide quick response (< 5 min)

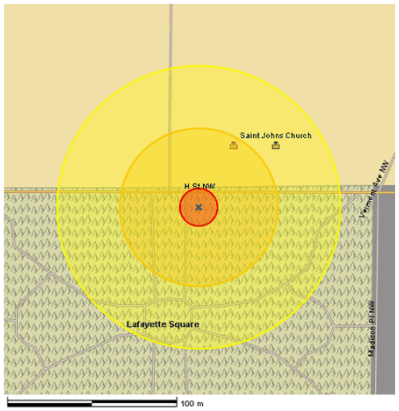


[1]Specialized Hazard Assessment Response Capability
[2]Federal Radiological Monitoring and Assessment Center

RDD Scenario Capabilities

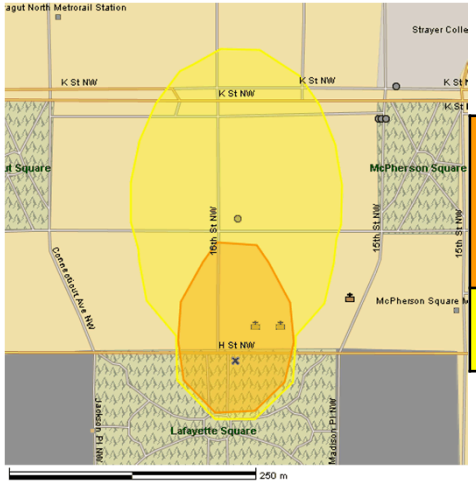
- Blast Effects
  - Physiological response
  - Range of shattered glass
- Radiation Protective Action Guides
  - Predicted evacuation and sheltering areas based on EPA/DHS guides
  - Worker protection areas based on exposure rate
  - Predicted relocation areas based on EPA/DHS guides
- Mitigation Considerations
  - Predicted effects when mitigation is used

Blast Effects



	Threshold for Fatalities (15 psi) Evacuate Personal Total Exposed Population: 17 Area: 402 m² Extent: 11.3 m
	Threshold for Injuries of Unsheltered Population (1.8 psi) Total Exposed Population: 199 Area: 6,865 m² Extent: 46.7 m
	Threshold for Glass Breakage (0.5 psi) Total Exposed Population: 557 Area: 22,232 m² Extent: 84.1 m

Radiation Protective Action Guides



	Evacuation of entire population warranted, unless additional unusually hazardous circumstances exist (exceeds 5 rem). Estimated Population: 410 Area: 26,300 m²
	Evacuation or sheltering normally initiated (1 to 5 rem). Estimated Population: 2,141 Area: 99,900 m²

Aqueous Foam and Gelled Water Mitigation

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Aqueous Foam

Gelled Water

Mitigation Benefits

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Aqueous Foam

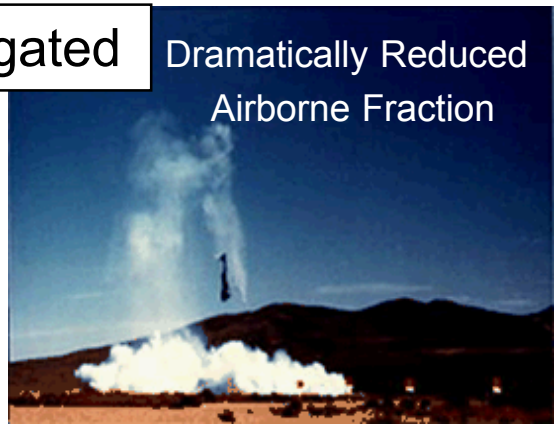
Gelled Water

Unmitigated

~28 psi

"Witness" vans at 30 feet from unmitigated and mitigated 100 lb detonations

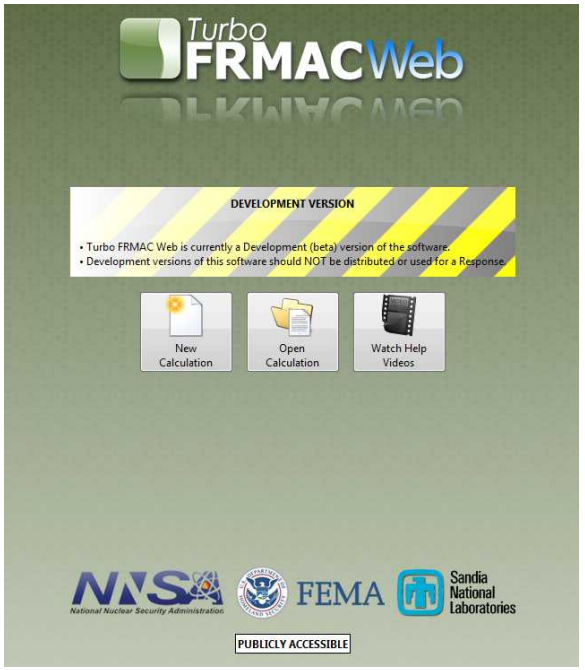
Mitigated

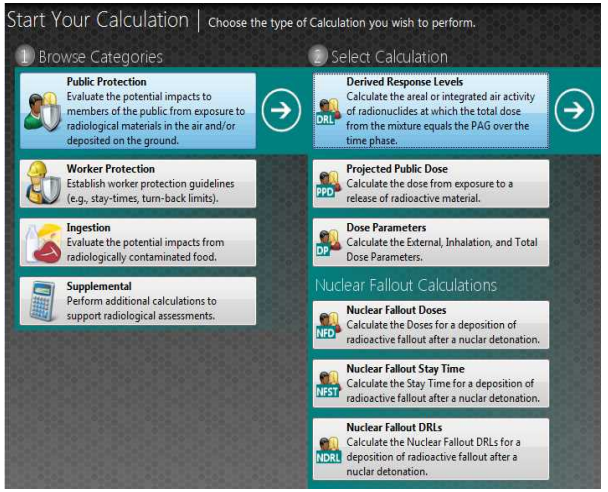


~1.7 psi

Turbo FRMAC

- Performs complex calculations to quickly evaluate radiological hazards during an emergency response by assessing impacts to the public, workers, and the food supply.
- Used to evaluate the hazard from a wide variety of radiological incidents to support Protective Action Decisions, such as:
  - Should a population be sheltered, evacuated or relocated?
  - When can a relocated population return home?
  - Might a food in an area need to be considered for removal from commerce?
  - How long can a worker remain in a contaminated area?
- Calculations are based on methods established by the FRMAC and are based on U.S. Government interagency consensus.





Briefing Products Were Tailored to Convey Key Information to Senior Officials and Federal, State, and Local Decision Makers

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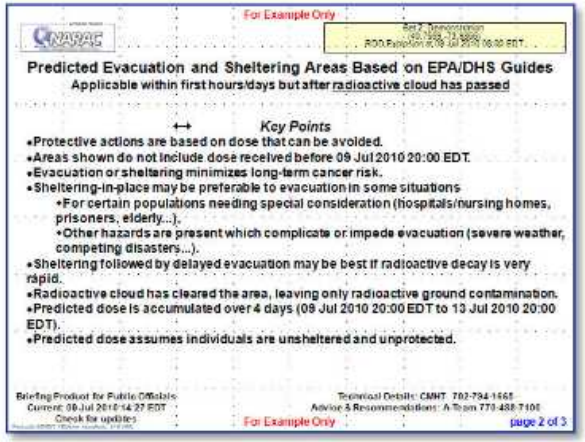
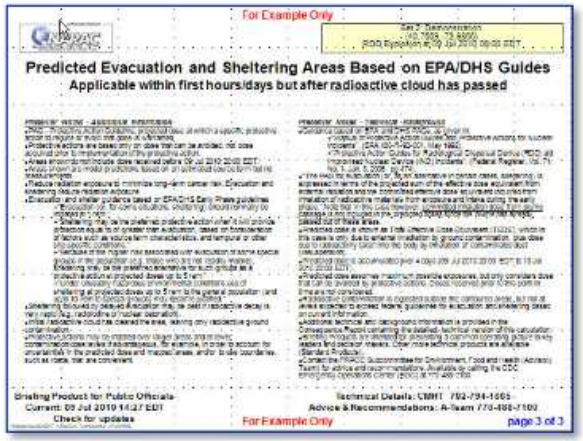
- Communicate key information about the impacts of hazardous releases and possible actions in non-technical terms to decision





Slide 1. Plot: Map with legend, notes on key briefing points, and assumptions

Slide 2. Key Points: Expanded list of key information concerning the product and/or relevant actions for consideration

Slide 3. Presenter Notes: Additional information and technical background (for use by the presenter, not intended to be shown)

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QUESTIONS

Example Problem If Time

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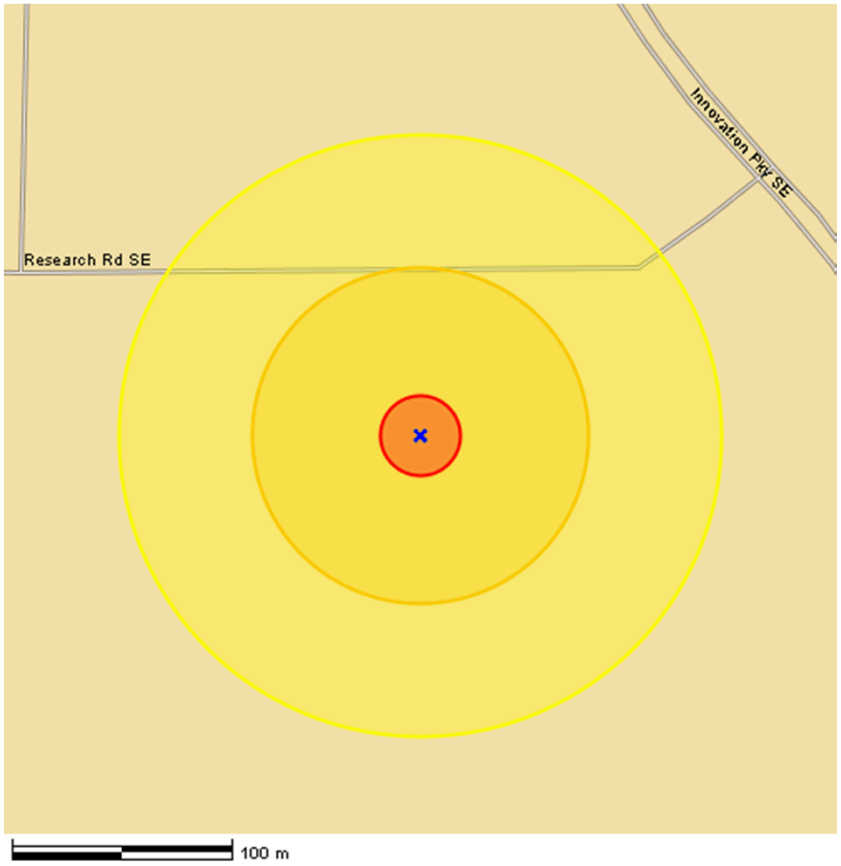
RDD Explosion at
Thu 10/22/2015 22:12 UTC (35.0547, -106.5275)

Predicted Blast Effects on Unsheltered Population

Explosive Dispersal Estimate: 50.0 kg C-4 Location: Albuquerque
Technical Basis for Explosive Amount: Planning Estimate



	Threshold for Fatalities (15 psi) Evacuate Personal Total Exposed Population: 0 Area: 1081 m² Extent: 18.6 m
	Threshold for Injuries of Unsheltered Population (1.8 psi) Total Exposed Population: 6 Area: 18461.5 m² Extent: 76.7 m
	Threshold for Glass Breakage (0.5 psi) Total Exposed Population: 19 Area: 59780 m² Extent: 137.9 m

Notes:

- Effects occur within a few seconds of the detonation. Actions taken after detonation are ineffective against these effects.
- Evacuation of this population should be considered. Phased evacuation for large populations may be necessary (work from the inside out).
- Evacuation recommendations should consider potential fallout direction.
- Population sheltering in substantial structures may have increased survivability.
- Building and structures in the area will affect actual impacts; and effects may not be uniformly radial as shown.

Assumptions:

- Assumes LandScan (2008) Population Database

Created: Thu 10/22/2015 22:36 UTC
Check for updates

National Nuclear Security Administration

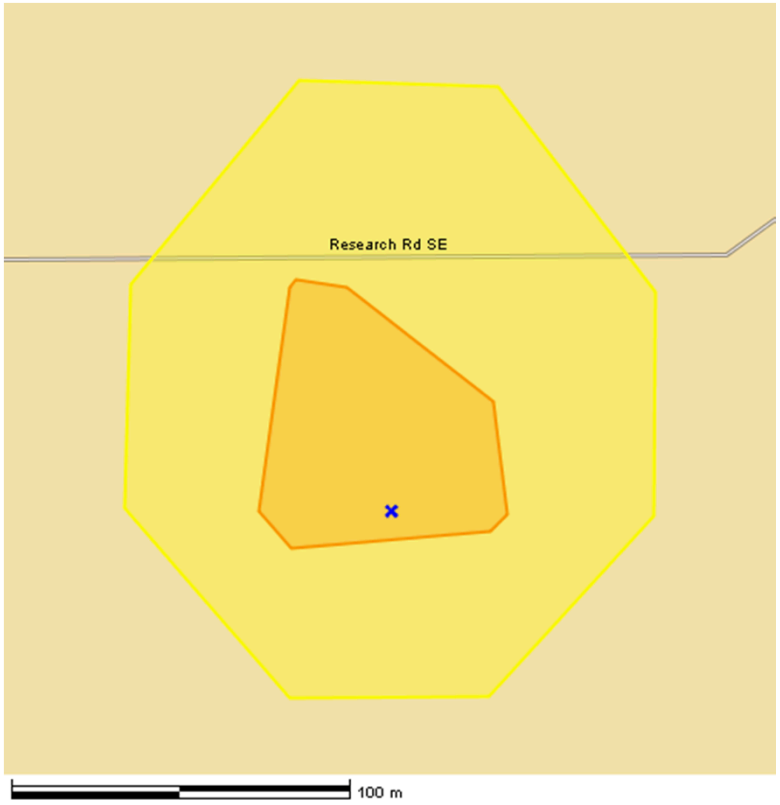
RDD Explosion at
Thu 10/22/2015 22:12 UTC (35.0547, -106.5275)

Predicted Evacuation and Sheltering Areas

Based on EPA/DHS Guides

Explosive Dispersal Estimate: 50.0 kg C-4
Technical Basis: Planning Estimate

Location: Albuquerque



	Evacuation of entire population warranted, unless additional unusually hazardous circumstances exist (exceeds 5 rem). Estimated Population: 4 Area: 6312.2 m²
	Evacuation or sheltering normally initiated (1 to 5 rem). Estimated Population: 5 Area: 34014.9 m²

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.**
- **If evacuation of this population is considered it might be necessary to implement a phased evacuation for large populations(work from the inside out).**
- **Radiation dose predicted for maximally exposed individuals and includes only dose from ground contamination over four days.**

Assumptions:

- **Assumes LandScan (2008) Population Database**

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Check for updates

National Nuclear Security Administration

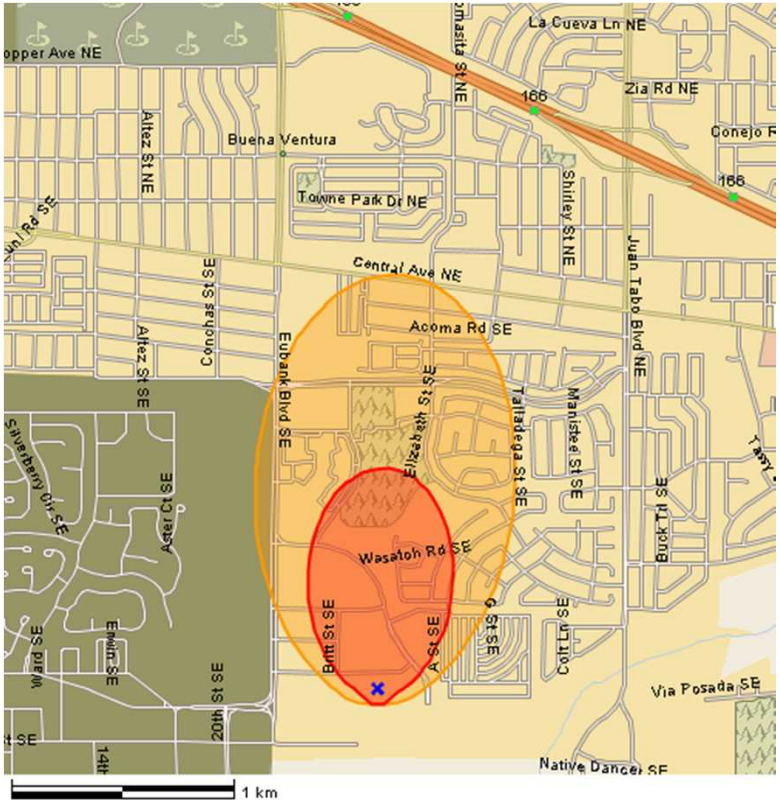
RDD Explosion at
Thu 10/22/2015 22:12 UTC (35.0547, -106.5275)

Predicted Relocation Areas, Due to Long Term Risk

Based on EPA/DHS Guides

Explosive Dispersal Estimate: 50.0 kg C-4
Technical Basis: Planning Estimate

Location: Albuquerque



	Relocation Recommended **Dose expected to be received during the 1st year exceeds 2.00 rem. Population: 215 Area: 0.8 km²**
	Relocation Recommended **Dose expected to be received during the 2nd or any subsequent year exceeds 0.500 rem. Population: 1,569 Area: 2.6 km²**

Notes:

- **Protective actions are based only on dose that can be avoided.**
- **Predicted dose assumes maximally exposed individual with no protective actions or mitigation.**

Assumptions:

- **Assumes LandScan (2008) Population Database**

Created: Thu 10/22/2015 22:36 UTC
Check for updates

National Nuclear Security Administration

Turbo FRMAC

- Performs complex calculations to quickly evaluate radiological hazards during an emergency response by assessing impacts to the public, workers, and the food supply. Turbo FRMAC can be used to evaluate the hazard from a wide variety of radiological incidents, including:
  - Radiological Dispersal Devices (RDDs)
  - Nuclear Power Plant Emergencies
  - Fuel Handling Accidents
  - Transportation Accidents
  - Nuclear Detonations
- These evaluations can be used to support Protective Action Decisions, such as:
  - Should a population be sheltered, evacuated or relocated?
  - When can a relocated population return home?
  - Might a food in an area need to be considered for removal from commerce?
  - When can a new crop be planted to minimize potential for contaminated food?
  - Should livestock be placed on stored feed?
  - How long can a worker remain in a contaminated area?
- Turbo FRMAC calculations are based on methods established by the Federal Radiological Monitoring and Assessment Center (FRMAC) in the FRMAC Assessment Manual. FRMAC-developed methods are based on U.S. Government interagency consensus.