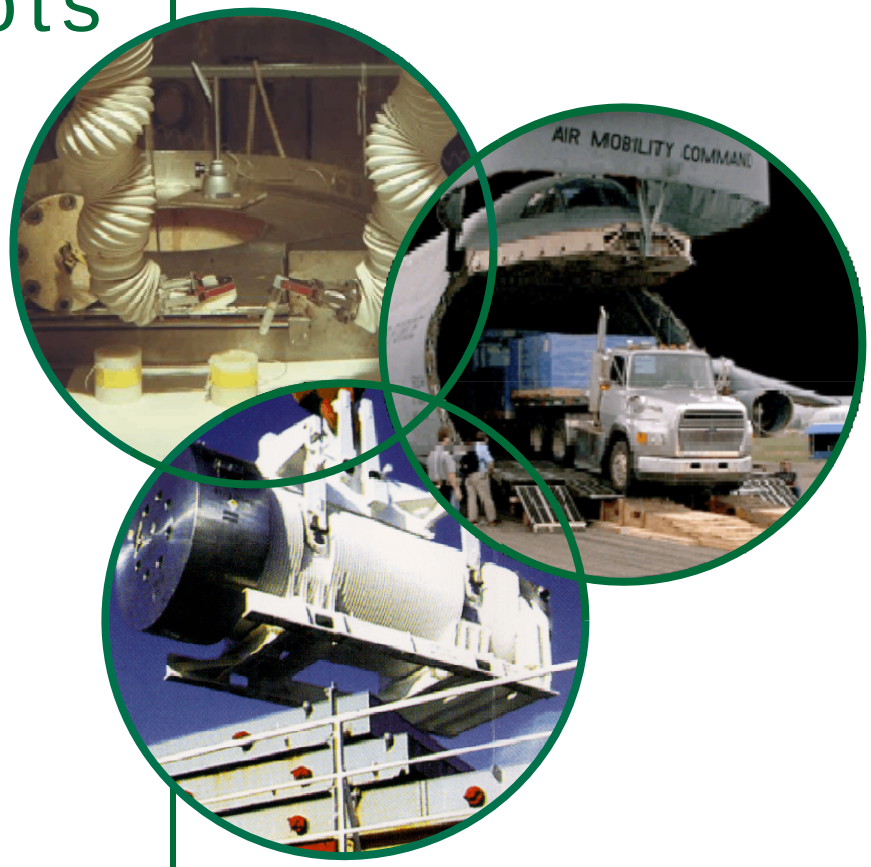
ORNL Nuclear Forensic Sciences: From Research to "Boots on the Ground"



July 22, 2011

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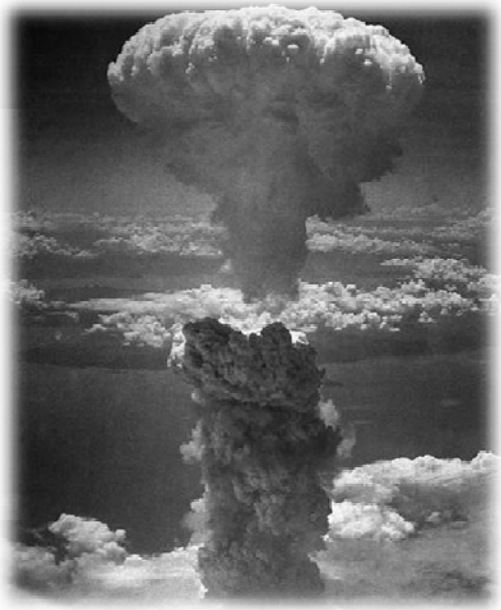
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

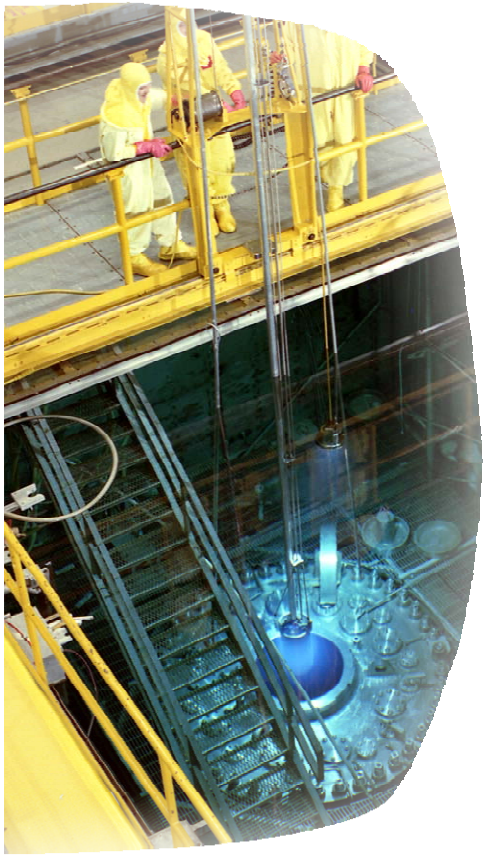
Big Picture Questions

- Who/where are the threats?
- Are threats credible?
- If nuclear materials are involved, whom do we hold responsible?
  - Who handled material and/or emplaced the device?
  - Did someone provide access to the special nuclear material or device?
  - For device, can design be reverse engineered?
  - For materials, can producer/fabricator be assigned?
  - Where was control lost?



Nuclear forensics data, law enforcement findings, and intelligence information must be fused to address these questions

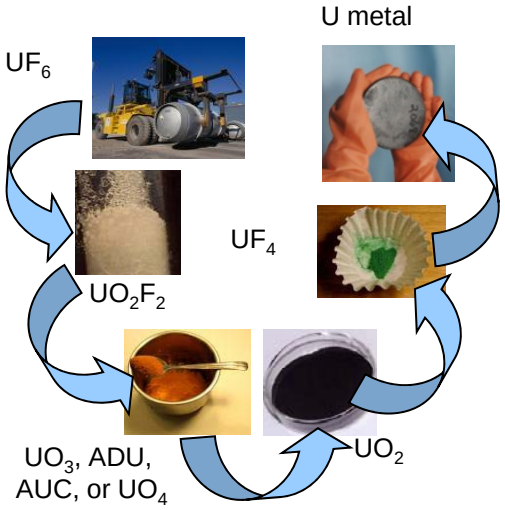
Nuclear Forensics Focus

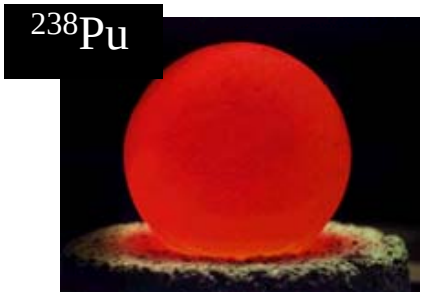


- Fissile material (SNM for IND and state weapons)
- Non-fissile radioactive material (RDD)
- Non-radioactive parts and pieces
  - Weaponization components
  - Improvised devices
  - Unique signatures of production and/or release
- Requires extensive lab effort and knowledge to correlate with findings

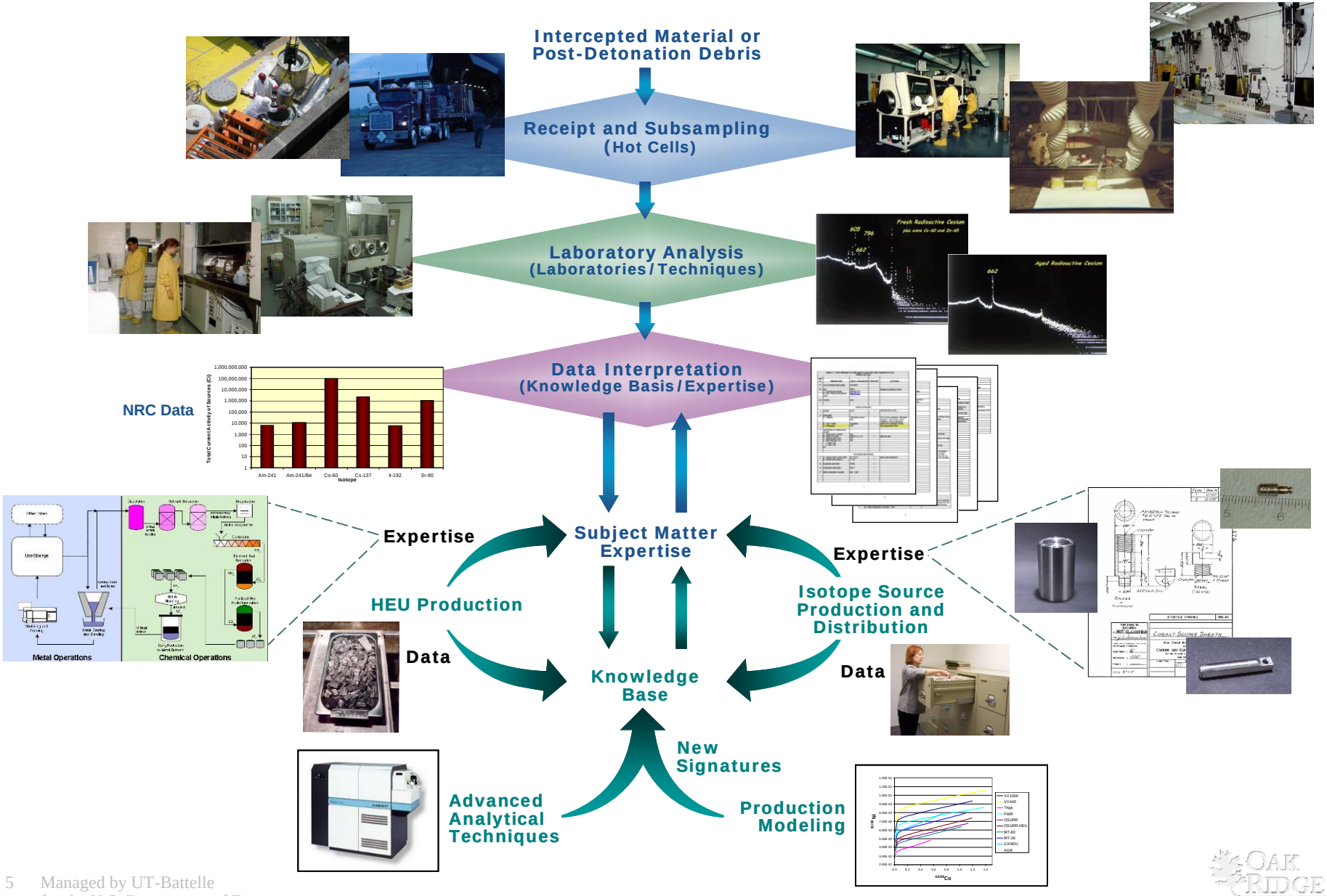
Materials of Interest

- Special Nuclear Material
  - ^{239}Pu, ^{235}U, ^{233}U
- Other Nuclear Material
  - ^{237}Np, ^{241}Am, ^{252}Cf, ^{6}Li, ^{3}H
- HEU (>90% ^{235}U)
- Other ^{235}U enrichments above natural
- Weaponization components
- Decay products (from purification or reprocessing)
- Fission products (from reactor operations or from detonation)
- Medical isotopes





ORNL Nuclear/Radiological Forensics Programs



Nuclear Forensics Capabilities based on Active Programs

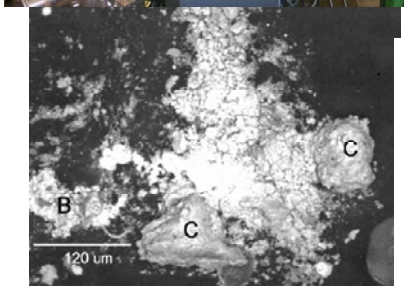
- Spallation Neutron Source
- High Flux Isotope Reactor
- Radiochemical Engineering Development Center (REDC)
- National Center for Computational Sciences
- Irradiated Fuels Examination Laboratory
- Irradiated Materials Examination and Testing Laboratory
- Low Activation Materials Design and Analysis Laboratory
- TRISO Fuel and Graphite Laboratories
- Fluoride Salt S&T Laboratories
- High Sensitivity Mass Spectrometry Development

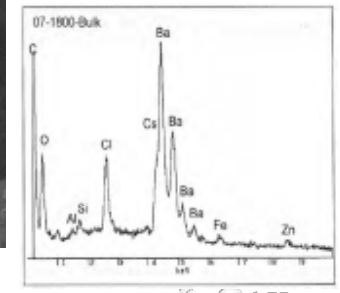
Sampling Science and Collection

- Samples from materials of interest may be interdicted
  - First Responder (at border or in country)
  - Collection of samples from interdicted material
- Samples may be:
  - Solid, liquid, or gas
  - Mixture
  - Off-gas after collection?
  - Reactive?
- Sampling methodology is a key aspect

Nuclear Forensics Analytical Approaches

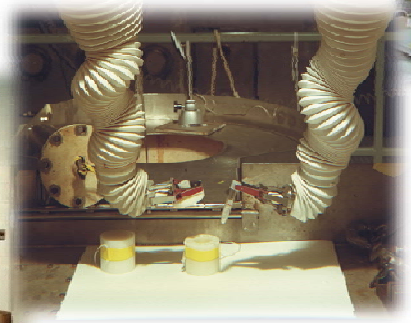
- Radioactive emission analysis
  - Gamma, Alpha spectrometry
- Chemical analysis of nuclear and non-nuclear materials
  - Physical characterization, electron microscopy, optical spectroscopy, chemical analysis
- Mass spectrometry
  - Sample preparation, radiochemical separation
  - High sensitivity, high precision analysis of mass-to-charge ratios





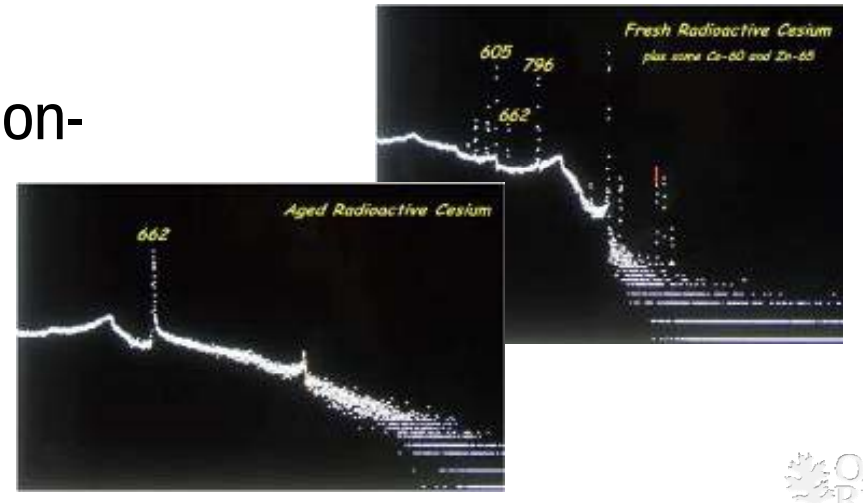
ORNL Radiological Facilities

- Analytical Chemistry Lab - receive and prepare beta-gamma emitting radioisotopes (^{60}Co, ^{137}Cs, ^{192}Ir, ^{90}Sr, etc.) and to conduct a full spectrum of analyses
- REDC –receive and prepare actinide (alpha and neutron emitters) radioisotopes (^{241}Am, ^{252}Cf, ^{244}Cm, ^{210}Po, ^{238}Pu, ^{239}Pu, ^{235}U, etc.)
- Fuels Examination Lab – metallurgical analysis of spent fuel and large sources



Radiochemical Analysis (Laboratories/Techniques)

- Alpha and gamma spectroscopy
- Liquid scintillation for beta material
- High precision mass spectrometry for measurement of RDD material isotopics and trace impurities
- High precision mass spectrometry for measurement of U and Pu isotopics and trace impurities
- Neutron activation analyses for non-destructive measurements

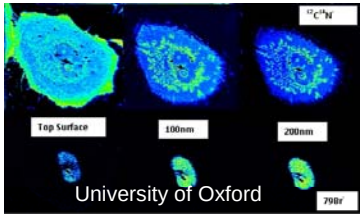


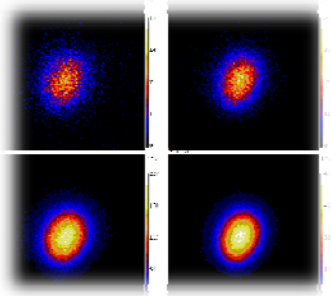
Development of Ultra-Trace Forensic Science Center

- Outcome: New scientific capabilities established at ORNL that are directed at nuclear forensics and other science missions
  - Relocate existing ultra-trace analysis capabilities
  - Invest in additional Secondary Ion Mass Spectrometry instrumentation and expertise

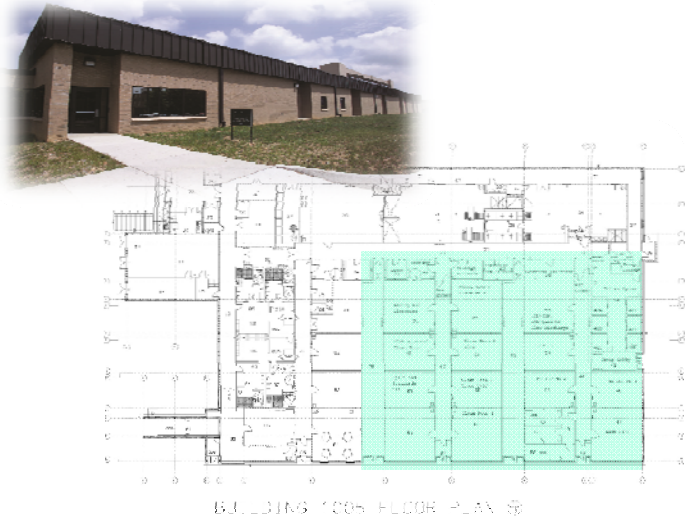
Existing ultra-trace mass spectrometry capabilities

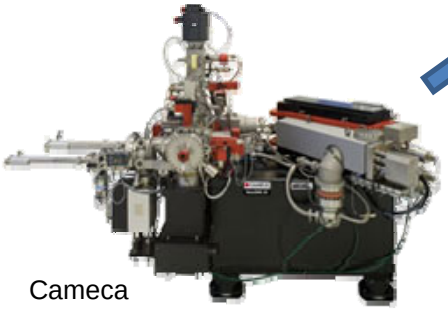
Cell biology



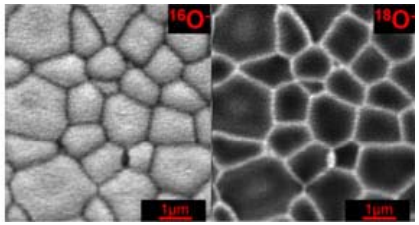


Heavy element analysis





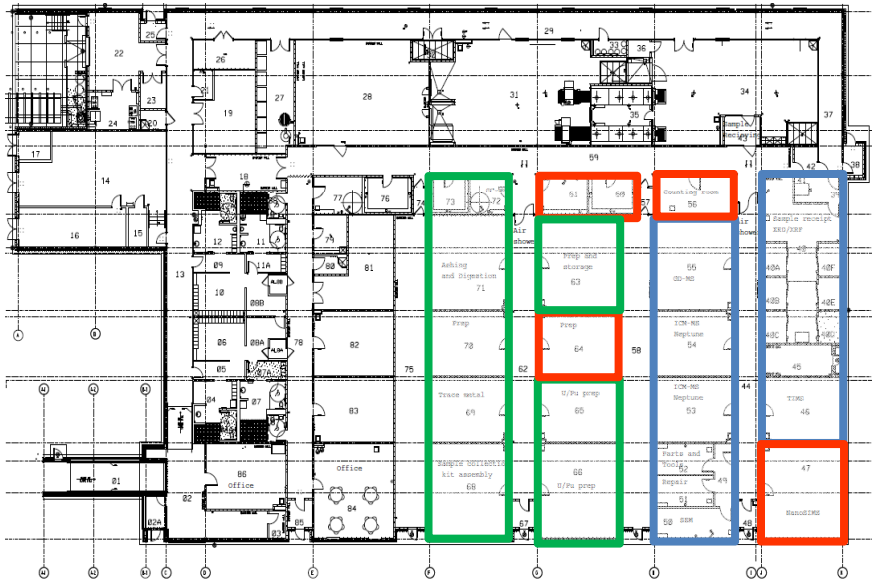
Cameca NanoSIMS



Materials science: Oxygen diffusion

Phased Approach for establishment of Ultra-Trace Forensic Science Center

- Sampling system development
  - Two labs for sampling system assembly and development
- Existing mass spectrometry systems
  - 6 labs for mass spectrometry (class 10,000 space for MC-ICPMS, TIMS, GD-MS)
- Trace sample preparation
  - Class 10,000 and class 1,000 space
- SIMS and class 100 clean rooms
- Future missions



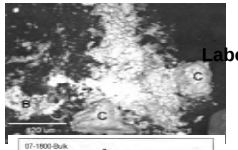
BUILDING 1005 FLOOR PLAN

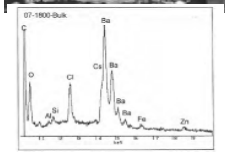
Phase I	Phase II	Phase III

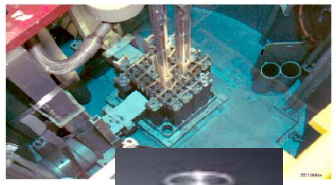
Application of Reactor Analysis to Nuclear Forensics

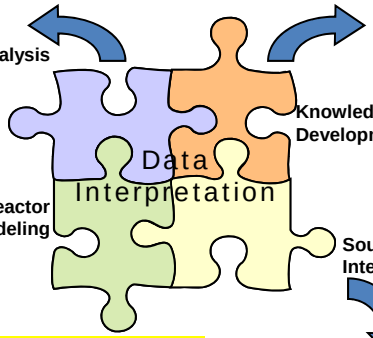
Develop accurate and efficient techniques to measure required nuclides

Data to connect source production/distribution and reactor operation with material origin







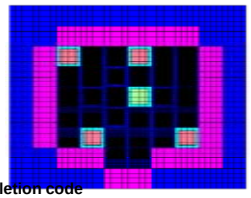


Oak Ridge Depletion/Decay Tools

Post-Detonation Determination of the Integrated RDD Source Strength (Proposed)

Coupled reactor physics with depletion/decay in 1D, 2D, 3D solutions

Integrated with Graphical User Interface to allow quick and efficient depletion via ORIGEN point depletion code

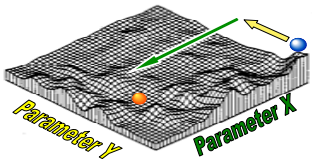


Field Data

Dispersion Models

Oak Ridge Inverse Depletion Theory Basics

Optimization on Residual Surface – residual is (model prediction – measurement)^2



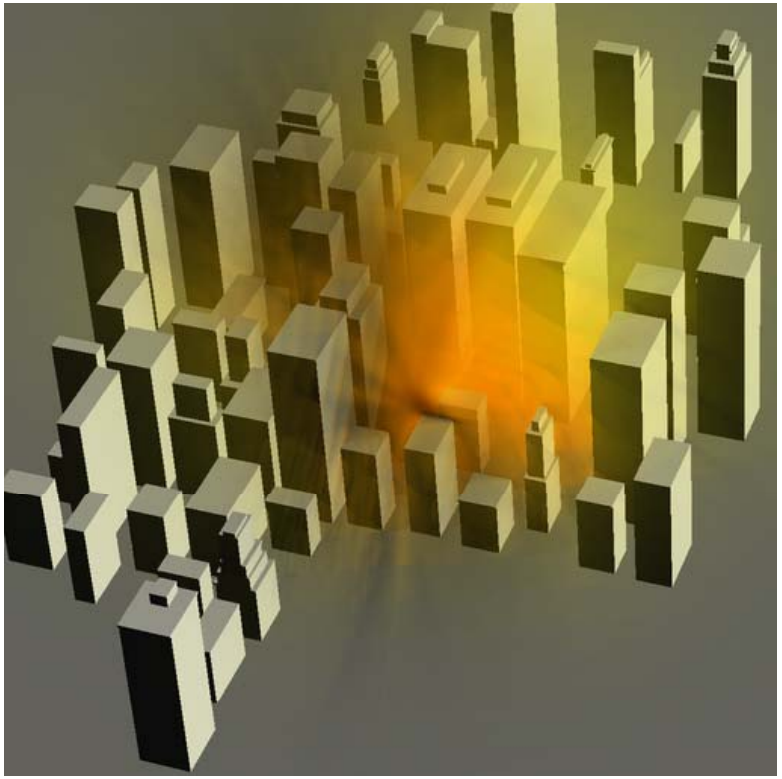
Effects and Actions

	Description	Level (uCi/m2)	Extent	Area	Population
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>100,000	98.1m	3,597 m2	1,080
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>10,000	286m	29,781 m2	7,680
	No guidelines specified. Possibly contaminated area. Use to confirm with monitoring surveys.	>1,000	767m	169,037 m2	18,400

Note: Areas and counts in the table are cumulative.

Modeling and Simulation:
Advancing radiation transport methods and codes

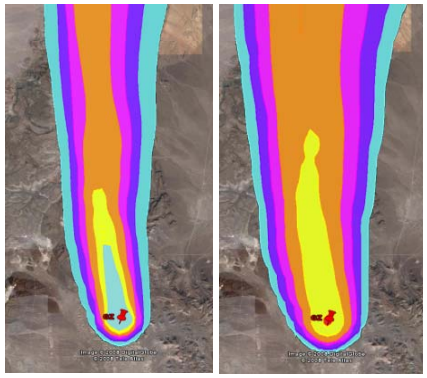
- Delivering the SCALE modular code system
  - Used worldwide for analyzing most aspects of the nuclear fuel cycle
  - Incorporates multiple software packages
- Developing hybrid methods that combine the best attributes of Monte Carlo and deterministic methods
- Exploiting the capabilities of high-performance computing and visualization systems to simulate impacts of a nuclear detonation
  - Planning and guidance for emergency response, consequence management, and forensics
  - Support for real-time decisions/activities following an incident



Times Square: Dose calculation

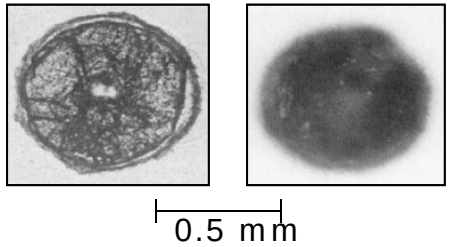
Collecting Nuclear Debris Samples:
Predicting quality samples while calculating dose to collectors

- Predict locations where ground concentrations are sufficient for collecting quality samples
  - Input: Yield, burst height, soil/urban environment, meteorology

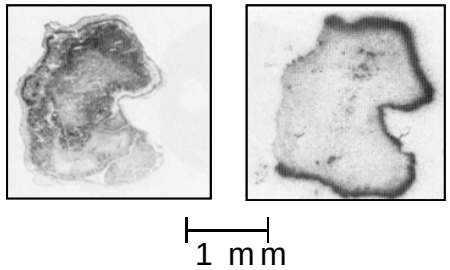


- Predict dose to collectors on basis of:
  - Predicted dose rates at locations of quality samples
  - Collection times and routes from mission planners
- Research model predicts cloud rise and particle dynamics, including fractionation effects important to fallout predictions
  - Support for decisions on evacuation and response

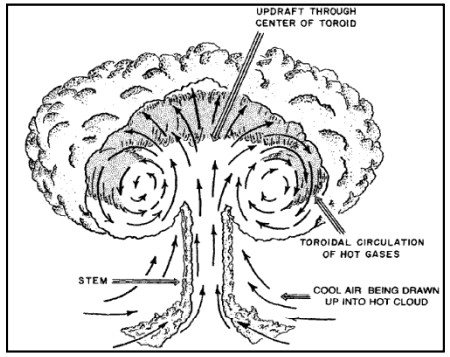
Thin section of spherical particle; radioactivity uniformly distributed



Thin section of irregular particle; radioactivity concentrated on surface

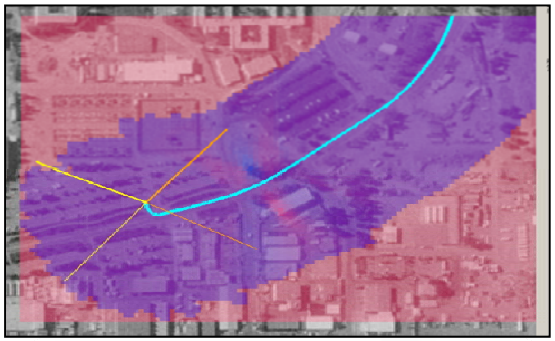


Toroidal circulation within radioactive cloud from nuclear explosion (artist's conception)



Summary

- ORNL Strengths in Nuclear Forensics
  - Nuclear processing operations
  - Subject matter experts
  - Advanced analytical capabilities
- Key Advancements and Investments
  - Establishment of Ultra-Trace Forensic Science Center
    - Enhancing detection limits for methods
  - Fielding technologies to enhance detection
  - Training "Boots on the Ground" personnel in forensics methods



Nuclear forensics is vital to U.S. and International nuclear security efforts

Questions?