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CBRNE Long Stand-off Detection

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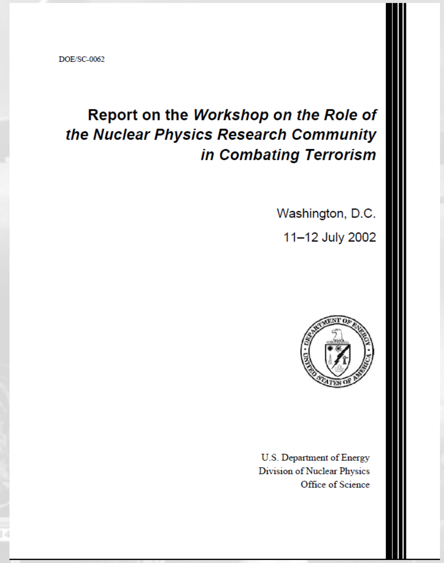
CBRNE Stand-off Detection

- Why long stand-off?
- Rationale for using accelerators
- Considerations for accelerator utilization in CBRNE
- Coupling of sources and detectors
- Future of long stand-off with accelerators
- Summary

Long Stand-off involves inspection at distances of > 3m

Migration to Long Stand-off Detection

- **9/11 and subsequent involvement in Afghanistan and Iraq highlighted the need for CBRNE detection**
- **Casualties from IEDs, suicide bombers, suspected use of cargo containers for shipment of WMD, generated need to inspect at larger distances**
- **Detection at short range is complex…..at stand-off distances, detection is an EXCEEDINGLY DIFFICULT problem**


DOE/SC-0062

Report on the *Workshop on the Role of the Nuclear Physics Research Community in Combating Terrorism*

Washington, D.C.

11–12 July 2002

U.S. Department of Energy
Division of Nuclear Physics
Office of Science

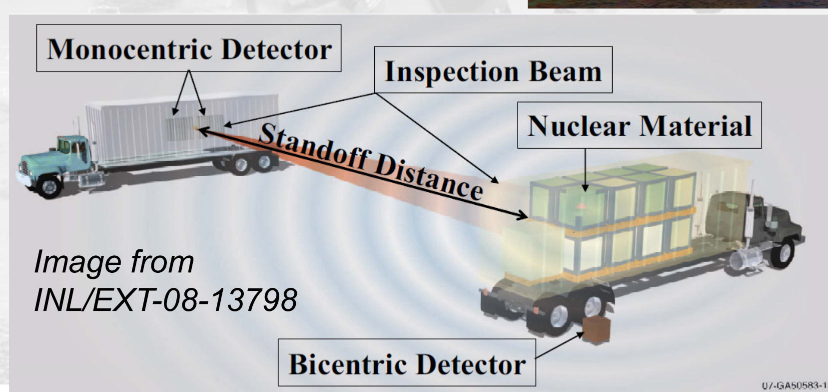


Image from INL/EXT-08-13798

Utilization of Accelerators in CBRNE Detection

- **Nuclear material detection (SNM)**
  – By far the largest effort involving particle accelerators
  – SNM not very radioactive
  – Fission signatures can travel large distances
- **Explosives**
  – Substantial effort to utilize neutron generators for detection of mines, IED, UXO
  – Relatively new area in millimeter wave, THz imaging
- **Chemical weapons**
  – Neutron generators
  – CW electron accelerators
  – Must identify isotopics
- **Biological weapons**
  – Biological weapons have few distinguishing isotopic components
- **Radiological material**
  – Little need for active interrogation
  – Inherently radioactive

SNM and explosives detection applications, by far, the largest users of particle accelerators

Why is Long Stand-off Active Inspection (AI) for SNM Important?

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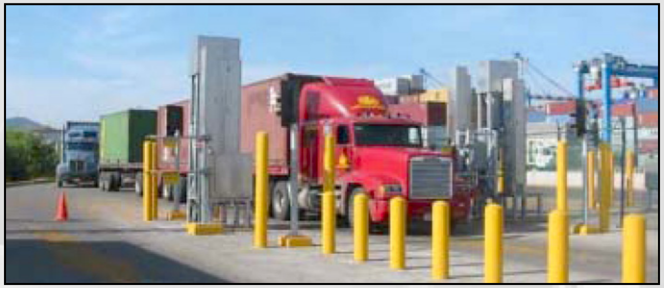
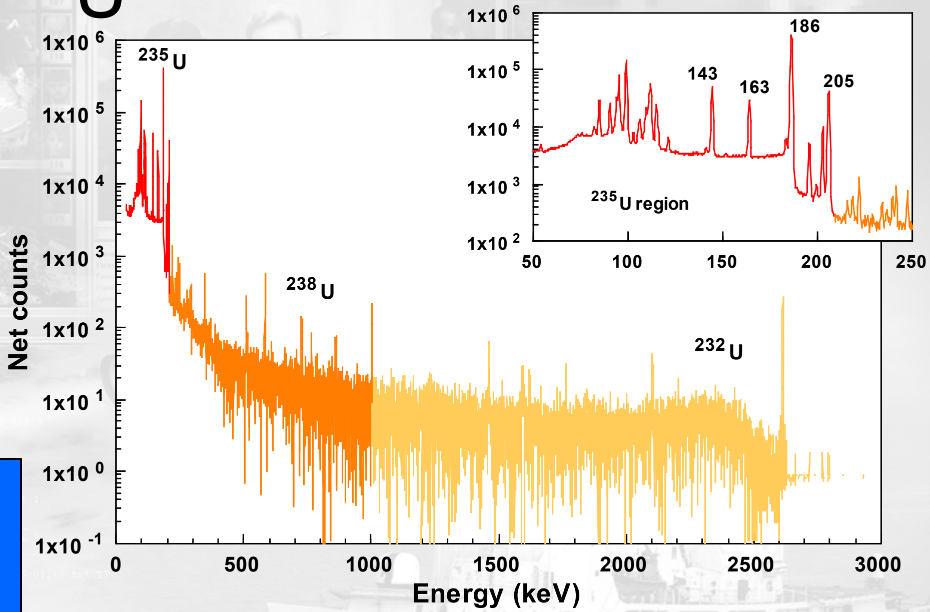
- SNM can be shielded from passive detectors
- HEU-based weapons tend to be more simple than Pu-based
- Centrifuged HEU has no ^{232}U contamination
- HEU emits few neutrons
- ^{238}U emits 12 n/s per kg
- Flexible ConOps





Detection of shielded SNM difficult at short ranges….extremely hard at large distances!

Components of a Long Stand-off Active Inspection (AI) System

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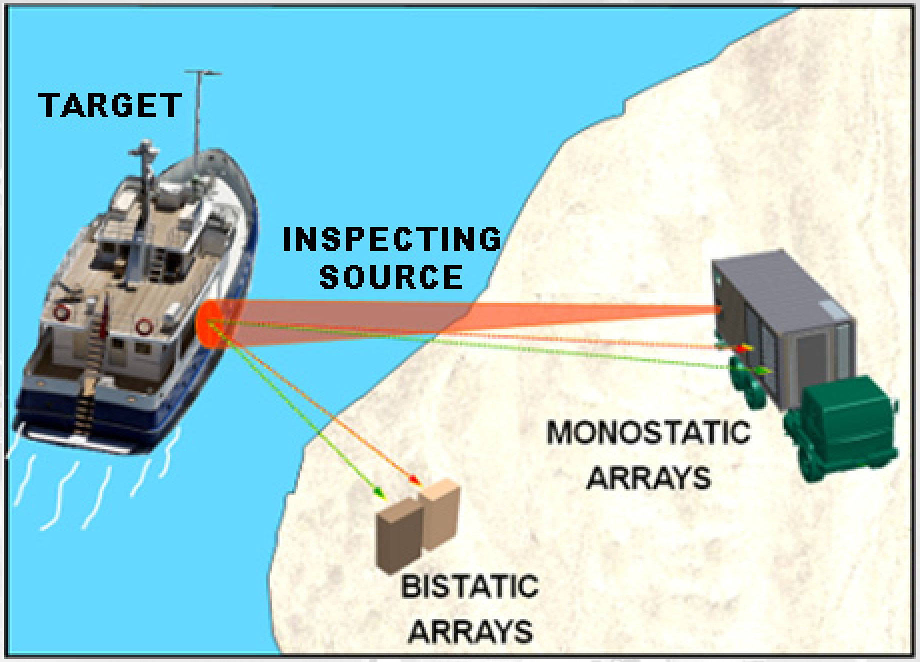
- System typically composed of a particle accelerator (inspection source); detectors
  - source includes x-rays, gammas, neutrons, high energy muons, high energy protons
- Detectors housed near inspecting source
  - (monostatic detectors)
- Re-locatable detectors
  - (bistatic detectors)
- Target is the item under inspection
  - Threat object will likely be shielded
  - Dose considerations important



Detection Systems Have Incorporated a Variety of Accelerator Types

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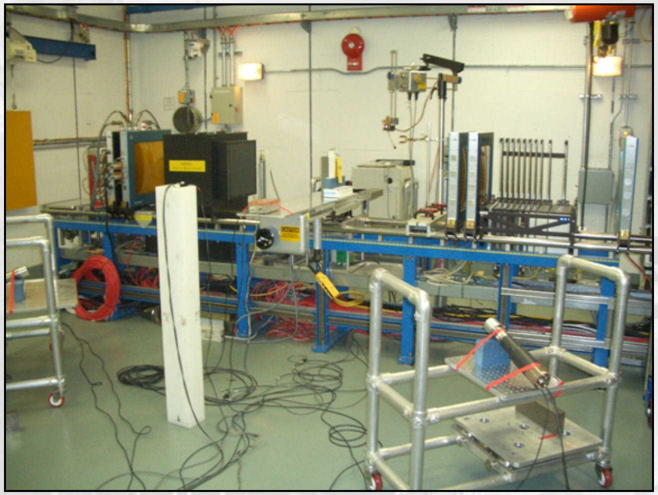
INL
6-12 MeV Linac
Source: INL



BNL
NSRL
Source: INL

LANL
LANSCE
Source: INL

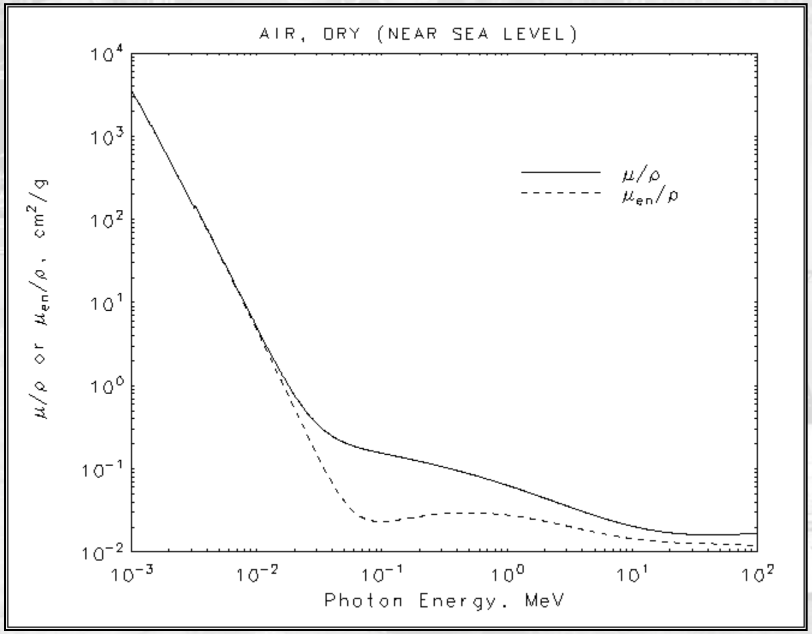
Industry
6-9 MeV Linac
Source: DNDO

What Do You Look For in CBRNE Detection?

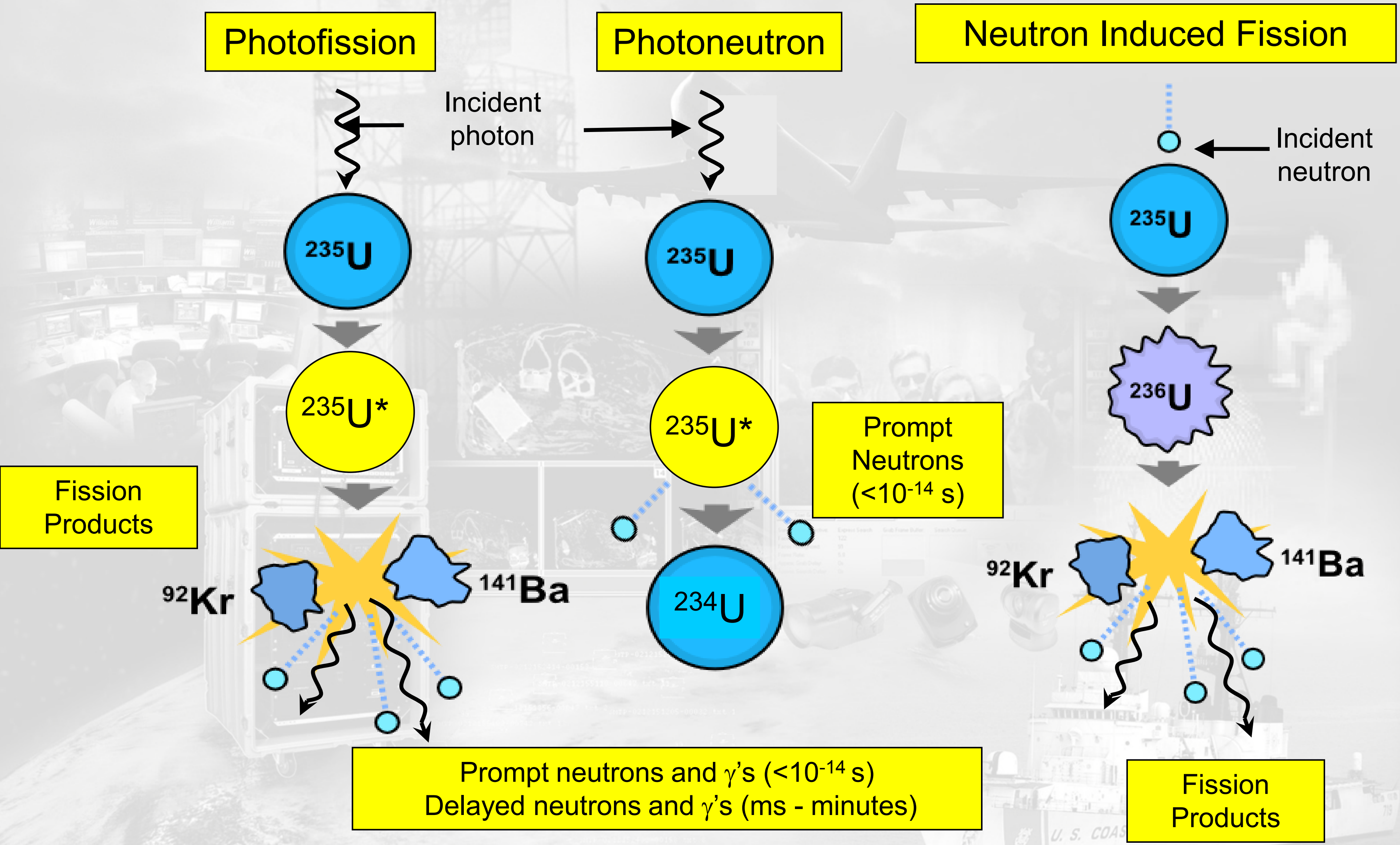
Neutrons: Reaction	Measured Particle	High-Energy X-Rays: Reaction
Inelastic Scattering, (n,2n) Absorption, Fission →	Prompt Gamma	← Scattering, Resonance Fluorescence, Photofission
(n,2n) Multiplication, Fission →	Prompt Neutron	← (γ,n), Photofission
Decay Following Absorption or Fission →	Delayed Gamma	← Decay Following Absorption or Fission
Decay Following Absorption or Fission →	Delayed Neutron	← Decay Following Absorption or Fission
Transmission/ Attenuation →	Radiography	← Transmission/ Attenuation
Transmission/ Attenuation →	Tomography	← Transmission/ Attenuation
Neutron Slowing Down via Σ →	Neutron Die-Away	← Photoneutron Slowing Down via Σ
Scattering →	Associated Particle	

Why Have Photons Dominated CBRNE Detection to this Point?

- **Photon ranges in air are sizeable, low attenuation in air**
- **Penetrating in target of interest**
- **Relatively “simple” and robust source**
  - Experience from medical community
  - Numerous medical sources
- **Neutron sources tend to be isotropic and fall off quickly with $1/r^2$**
- **Other types of inspection may be possible**
  - Explosives
  - EFPs
  - Chem/Bio



Photonuclear Basics in SNM



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Photon Inspection: Then and Now

HISTORIC

- Use of existing medical therapy machines
- Little concern for background neutron production from converter
- Poor knowledge of beam energy and current
- Inflexible pulsing structures
- High-Z converter was the norm
- Electron energies 6-10 MeV
- Near-field inspection

CURRENT

- Dedicated accelerators
- Inspection energy critical
- Current must be known
- Pulse structure must be variable
- Production target tailored for applications
  - Especially for long stand-off
- Electron energy > 10 MeV
- Proton/muon energies of hundreds of MeV to a few GeV
- Far-field inspection
  - ….As far as we can get

Primary Considerations for Long Stand-off Active Inspection

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- Useful signal is often a very small component of a very large radiation background
  - Sensitivity and specificity are needed
  - Would like to have energy, particle type, and timing information
- Extremely high instantaneous count rates push DAQ systems and detector electronic
  - Shielding detectors not always the answer
- Detectors in proximity to accelerators or pulse-power sources will encounter EMI
- Many long stand-off systems will be designed for continuous operation in non-climate controlled, outdoor environment

Count Rates May Be Too High: Detector Response "Too Slow"

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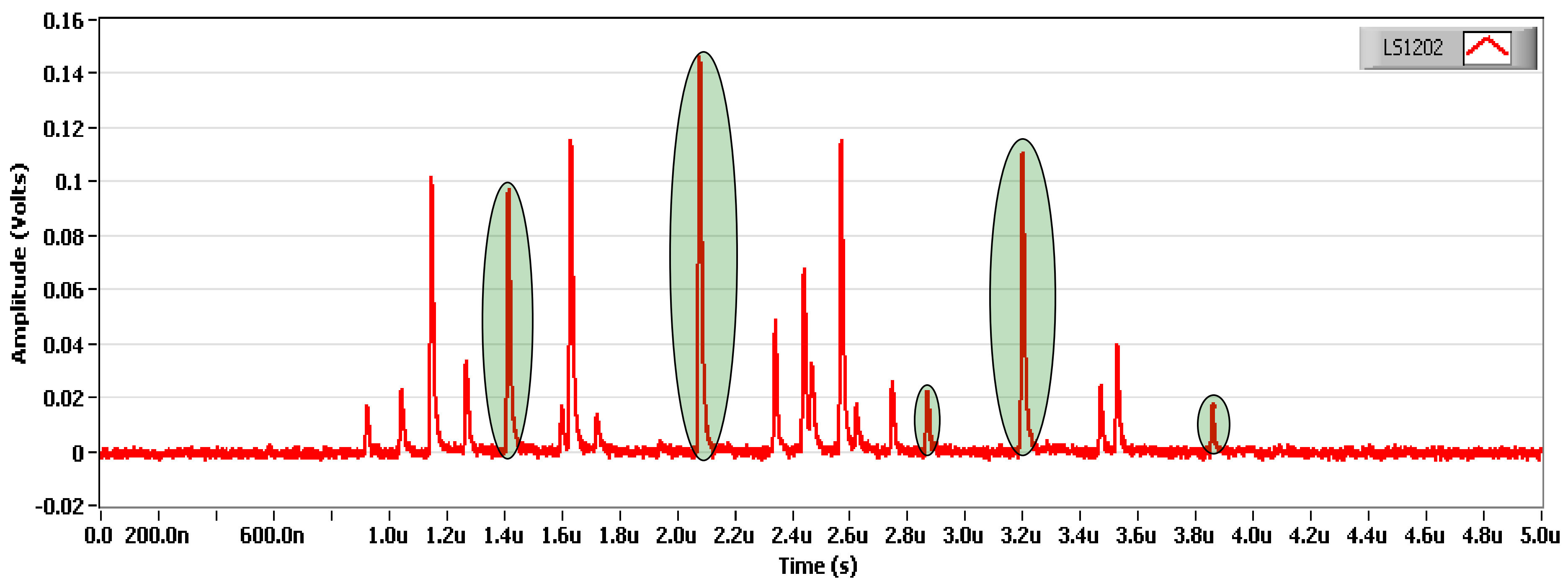
- ^{3}He requires hundreds of μs for moderation
- Liquid scintillators require few hundred ns for conventional PSD
- Count rates >3.3 x 10^6 cps reduce viability of PSD



Count rate during 3 μs 9 MeV pulse ~6 x 10^6 cps

What is Different about the AI Environment?

- Active interrogation systems often involve the operation of detectors in environments for which they have not been designed

- Detectors must be matched with overall system requirements and <u>source</u> performance

- AI systems generate effects not normally encountered
  – copious amounts of long-lived (>μs) light states in scintillators
  – photon activation; high dose effects
  – exotic neutron and proton reactions

Long-lived Light States in Scintillators

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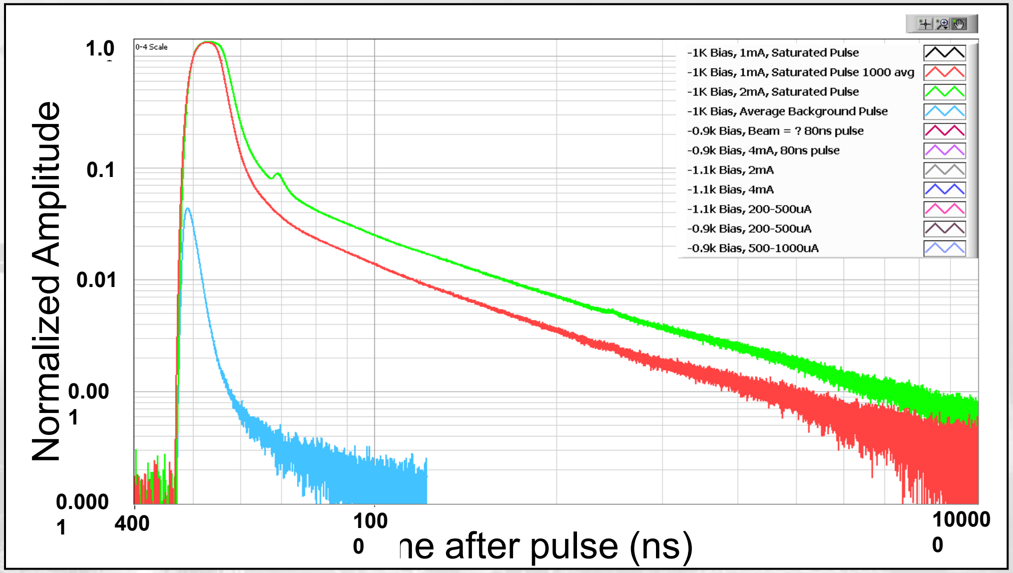
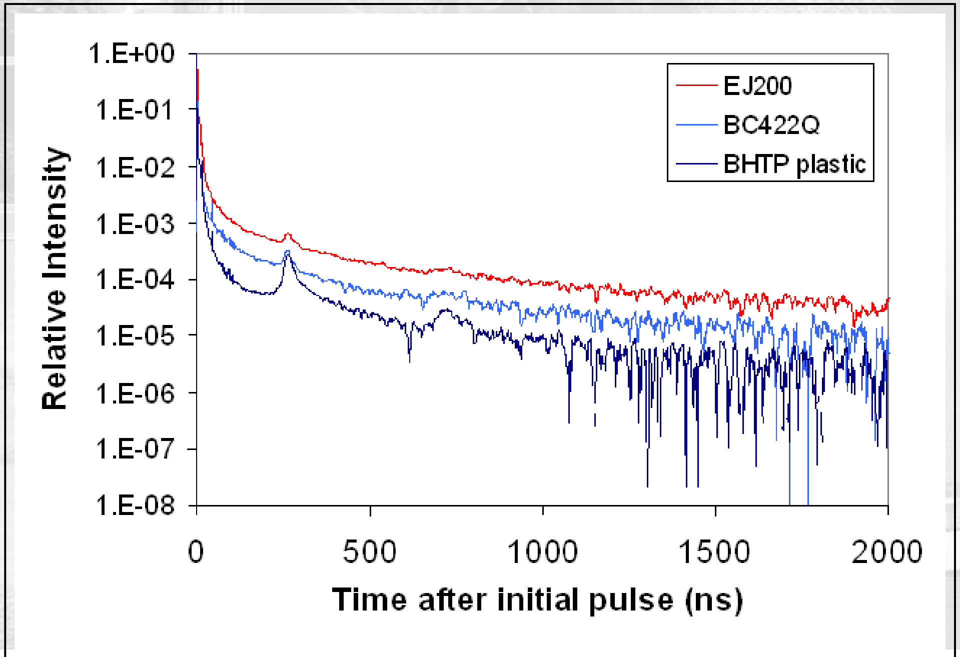
- All scintillators exhibit long-lived states
- In normal counting with single pulses, long-lived states less important
  - 1 MeVee generates approx. 10^4 visible photons
- Active inspection can easily deposit >10’s MeVee in the flash
- Even if the PMT can recover, light is present in the scintillator





What's at Stake?

- Dose on target
  – Nearly always concerned about imparted dose on target
- Dose around accelerator
  – Operator safety (< 5 mRem/hr)
  – Civilian safety (< 50 μRem/hr)
- Off-axis dose
  – Unintended irradiation
  – Ability to raster and locate beam precisely
- Sensitivity
  – Time of inspection
  – Minimum detectable amount
  – Stand-off distance

What is Needed For Good Dose Control Near Target Object?

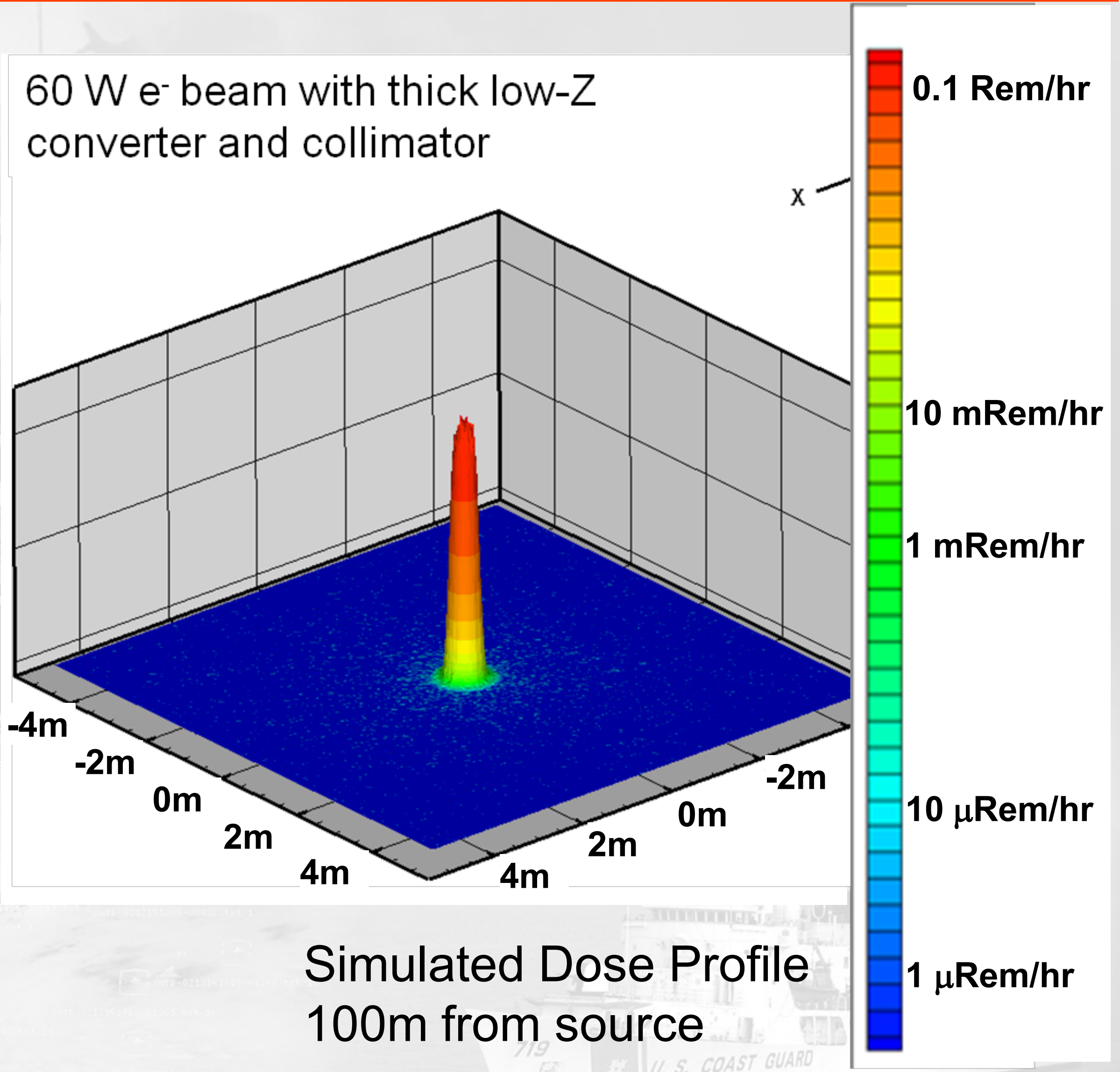
- **Good emittance in the accelerator**
- **Robust targeting and tracking system**
  – Automated control tied to beam control and steering
- **Low-Z converter of proper thickness**
  – Preferential forward directionality
  – Good material both thermally and mechanically
  – Large neutron separation threshold

Considered	Rejected
Water, C, Al, Cu	Be, Li, B, Fe

- **Relatively massive collimator**
  – Collimation does not lead to greater sensitivity!!

What is the Trade Off?

- **Sensitivity**
  - Collimation does not put more source particles on target!!
    - Does limit induced background
  - Collimation will nearly always degrade sensitivity
  - Sensitivity is directly proportional to the dose on target for a given detector area
- **Dose control**
  - Off-axis dose control requires careful beam steering and collimation
  - Operator dose control can be managed much more easily than off-axis dose; operators can always be remote!



Simulated Dose Profile
100m from source

Future of CBRNE Long Stand-Off Detection

- **Applications utilizing broad spectrum, pulsed bremsstrahlung photons will transition to other source types**
  – Mono-energetic photons
  – CW sources
  – High energy protons or muons
  – API neutron generators
- **High gradient accelerators will be necessary**
  – GeV energies in transportable accelerator
  – Must be ruggedized
- **Large area, imaging detectors will be required**
  – Overcome isotropic emission
  – Extract small signal from large background
  – Combine many sensor types (nuclear, visual, IR, THz, radar)
  – Build on technology from high energy physics community
- **Accelerators and detectors must be designed in conjunction with each other**

Novel Inspection Sources

- Nearly mono-energetic gamma-ray sources (LLNL)
  – Inverse laser-Compton scattering source
  – 120 MeV S-band accelerator, high power laser source
- Superconducting cyclotrons (MIT)
  – High energy >200 MeV protons
  – Operating at 7-9 T
  – mA average current
- FFAG (Passport Systems)
  – 10-15 MeV CW electron current
  – Nuclear Resonance Fluorescence
- High-Gradient Accelerators (Numerous Investigators)
  – Laser wakefield
  – Dielectric wall induction accelerators

High-Energy Accelerator Structures Ruggedized for Field Deployment

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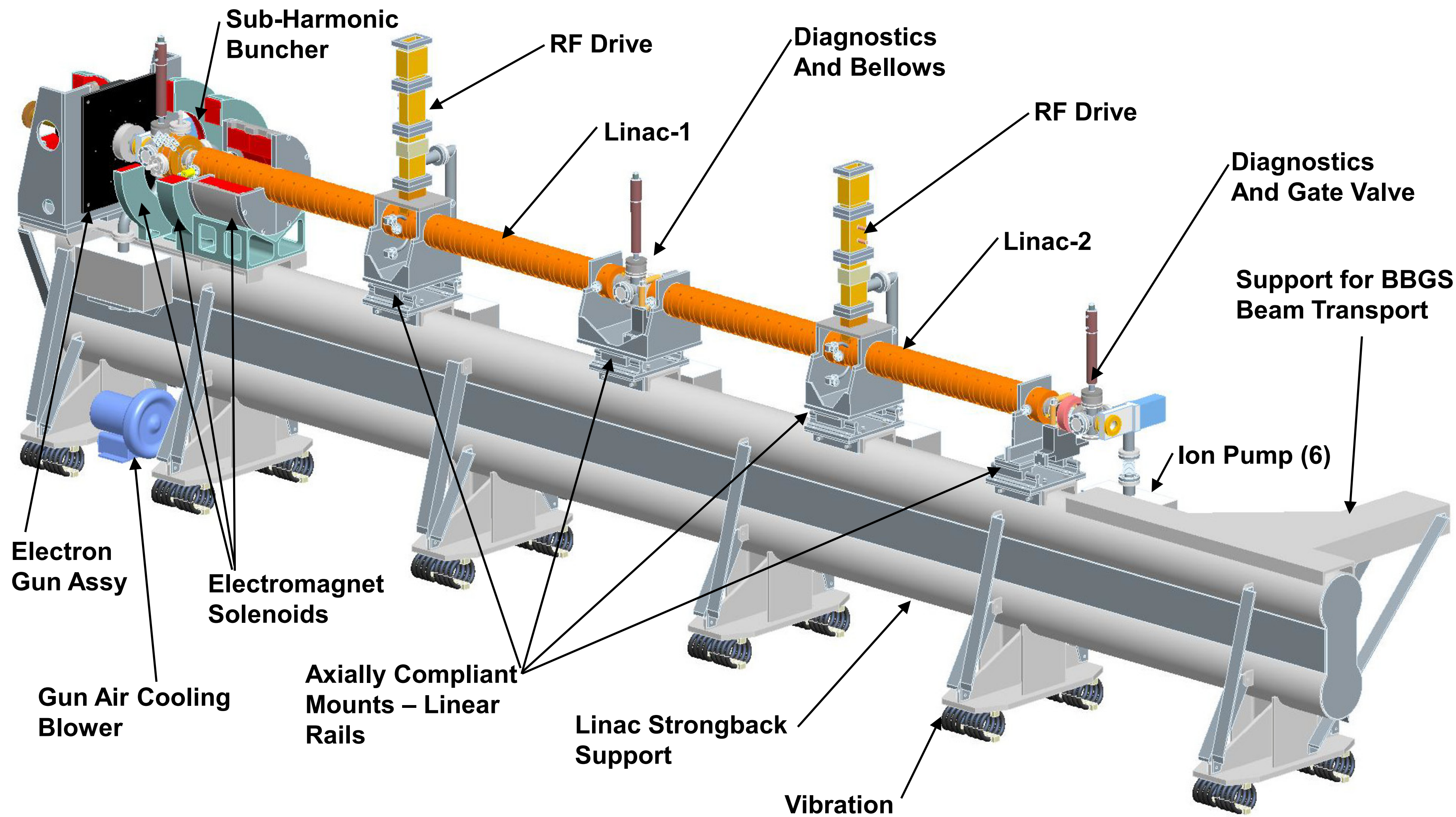
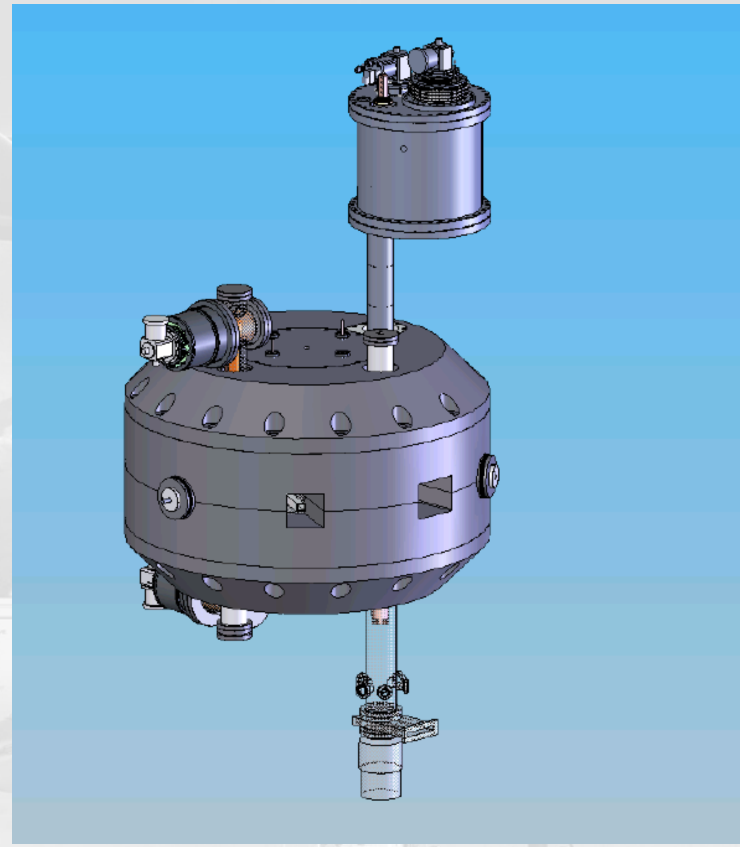


Courtesy of AES

Compact Superconducting Cyclotrons

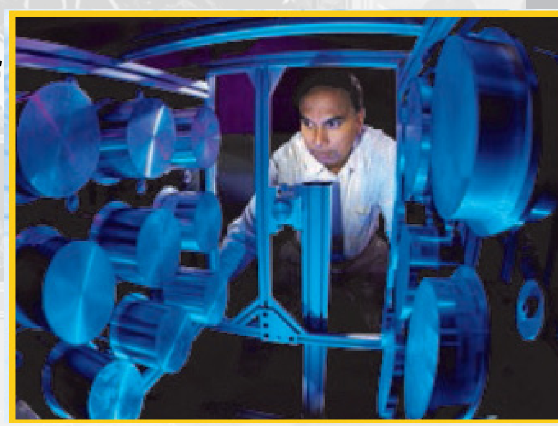
- **Compact (few cubic meters) B_0 7-9 T**
- **Transportable**
  - Minimize mass and power
- **Not tethered to a helium liquifier**
  - HTS leads
  - Many conductor types
- **Full acceleration in a single accelerator stage**
- **At high field (B_0 > 6 T) all 3 types possible: classical, synchrocyclotron, isochronous**
- **10-1000 MeV protons and heavy ions**
- **Two machines under development at MIT**
  - 10 MeV p / 5 MeV d
  - 250 MeV p

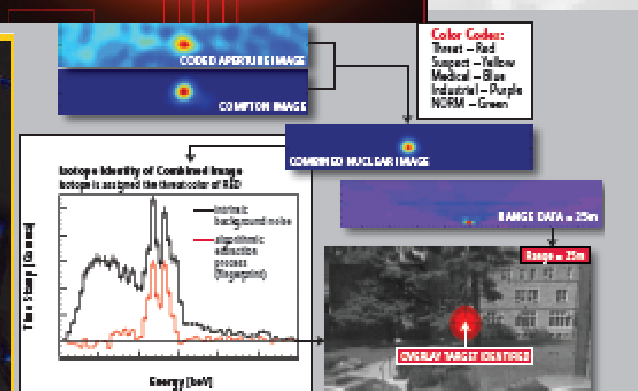


Source: MIT

Large Area Detectors Vital to Long Stand-off

- **Large area detectors critical for stand-off detection**
  - Surface areas >10 m^2
  - Combine neutron and gamma imaging with visual, IR, radar
- **Current imaging systems require tiling of smaller**
  - 25cm x 25 cm units
  - Cost ≈ \$1M per m^2
  - Must draw from high energy physics experience
- **Require adjustable rather than fixed FOV and resolution**





Source: Sandia National Lab

In Summary

- **Long stand-off detection for CBRNE will continue to play a role in domestic and international security**
- **Particle accelerators will be at the center of active inspection systems**
- **Next generation particle accelerators could potentially open up new ConOps**
  - Higher gradient
  - Small footprint
  - Energy selection
  - CW operation
- **CBRNE detection systems must be designed with both sources and sensors in mind**