U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration
Defense Nuclear Nonproliferation

Defense Nuclear Nonproliferation Research & Development

Consortium for Verification Technology 2016 Workshop

LBNL Research Highlights

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BERKELEY LAB

CONSORTIUM FOR VERIFICATION TECHNOLOGY

DNNG
Detection for Nuclear Nonproliferation Group

Assessing impact of monoenergetic photon sources on nonproliferation applications

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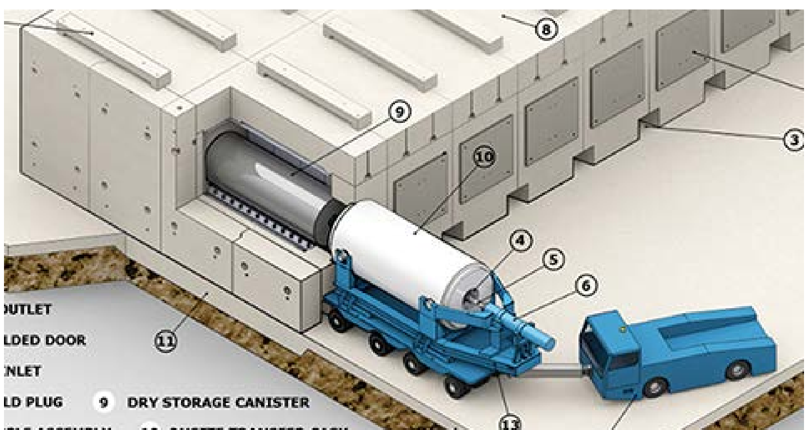
- Goals
  - Identify a broad range of applications where Monoenergetic Photon Sources (MPS) may have a high impact and prioritize.
  - Assess application requirements (system capabilities and CONOPS constraints), current capabilities, and gaps.
  - Derive photon source requirements (e.g., energy, energy spread, divergence, intensity)
- Applications selected for detailed modeling/ assessment:
  - Screening and interdiction – cargo containers, trucks (lead: LLNL)
  - Detection of hidden SNM – single-sided inspection (lead: INL)
  - Warhead/dismantlement verification (lead: PNNL)
    - Related: tomography for Stockpile Stewardship
  - **Spent nuclear fuel dry-storage cask verification (lead: LBNL,UM)**

Safeguards dry-storage cask verification
Large, shielded cask must be penetrated

- **Re-verification of cask content (missing fuel bundles) by MPS transmission measurements**
  - Scattering and attenuation severe
  - Pencil beam reduces scatter contribution
  - Fuel background mitigated by gating detector with MPS
  - Infrequent need – long measurement times acceptable

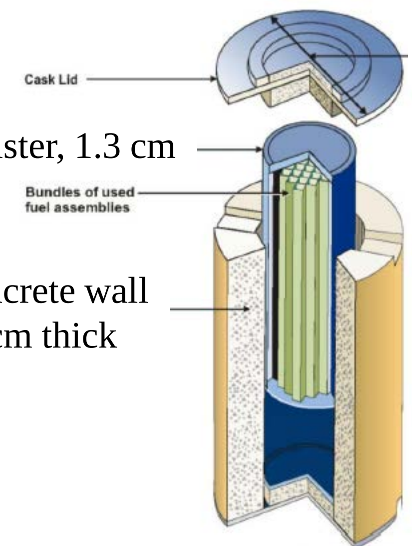
- **Dry-storage cask designs vary:** thick steel casks, steel storage canister in concrete overpack or in storage module, large and small fuel bundles (assemblies)



NUHOMS EOS (Areva TN) Horizontal storage modules

~330 cm dia.

Steel canister, 1.3 cm



Concrete wall
68 cm thick

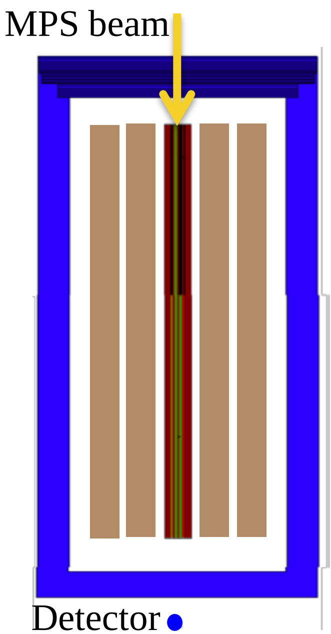
HI-STORM 100

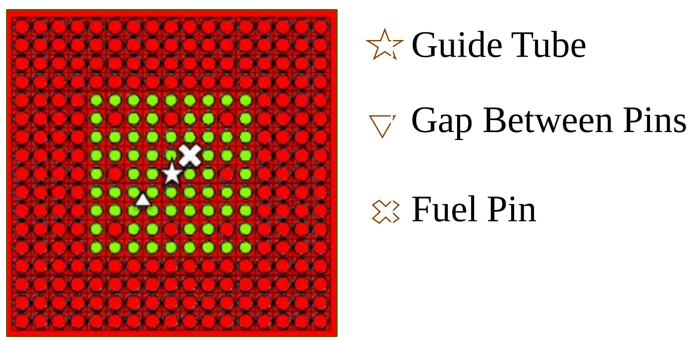
Overall Length: 197 to 225 in.
Loaded Weight: 360,000 lbs.
Typical Payload: 24 PWR Bundles

* Storage and Transportation

Safeguards dry-storage cask verification MPS pencil beam transmission sensitive

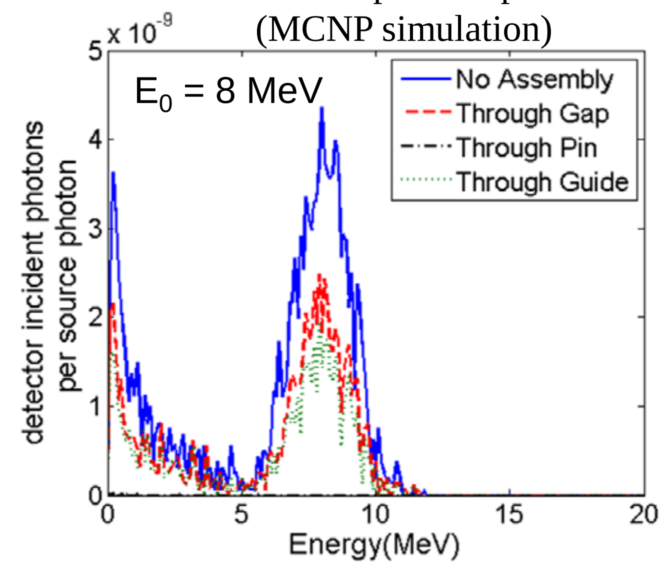
- **Longitudinal transmission scan can verify assembly occupancy**
  - Short measurement time per spot
    - At 3×10^8 photons/pulse, 1 kHz, 10^{-8} transmission → 3000 photons/s
  - Missing single pin detectable with narrow divergence beam (3.5 mrad)





Transmission probabilities (MC-10 cask, MCNP simulations)	
No assembly:	1.4×10^{-6}
Centered on gap:	7.6×10^{-7}
Centered on pin:	4.5×10^{-10}

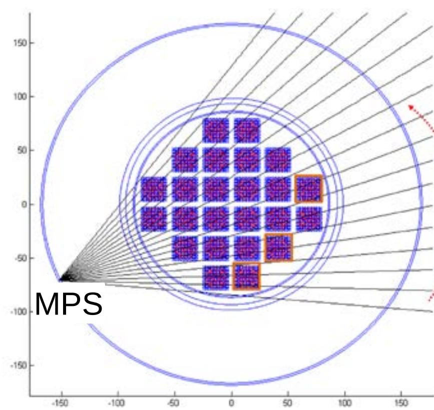
Transmitted photon spectrum (MCNP simulation)

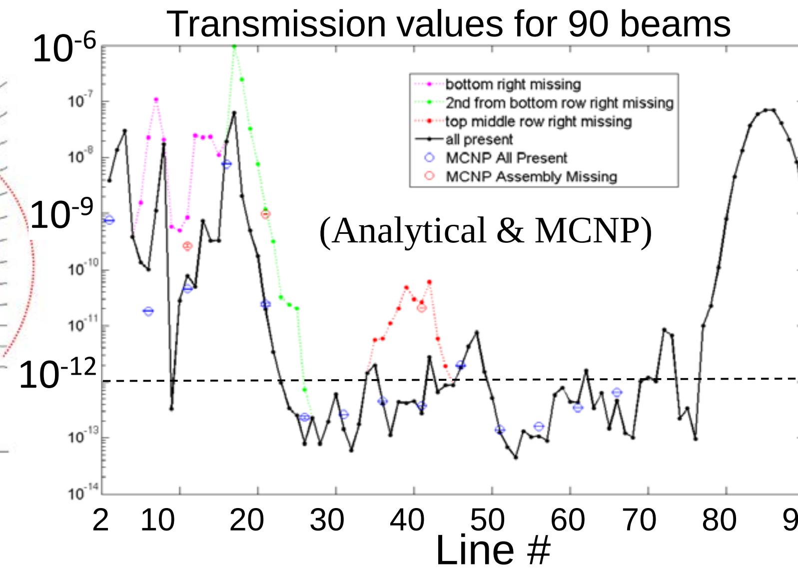


Safeguards dry cask verification
MPS enables transverse transmission scan

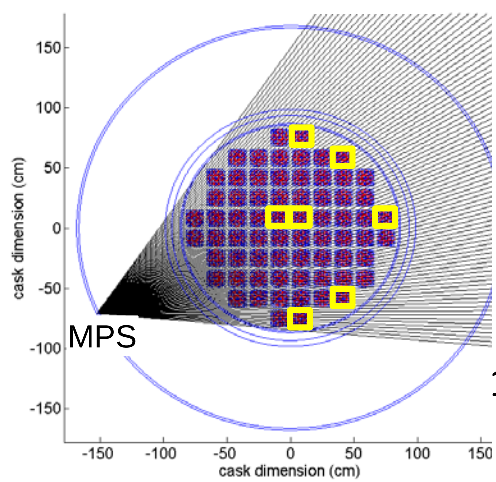
- **Transmission calculated analytically**
  - Check against MCNP simulations shows good agreement
  - Several scans angles and cask types evaluated
- **Missing assemblies can be detected:**
  - ~10x higher transmission
  - Transmission > 10^{-12} if assembly missing
  - At 10^{-12} transmission, 3×10^{8} photons/pulse, 10 kHz → 3 photons/s
  - Acceptable measurement times

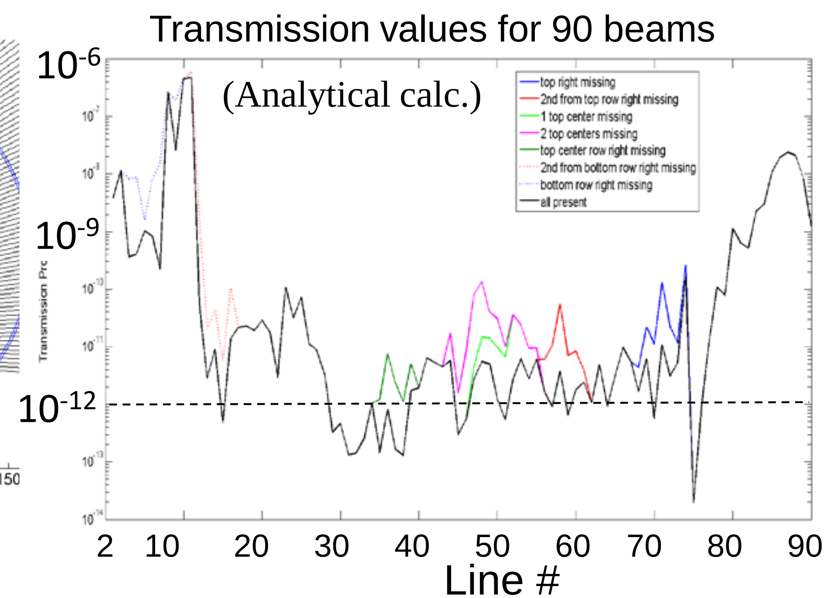
HI-STORM MPC 24





HI-STORM MPC 68





General Conclusions

- **MPS with narrow energy and angular spreads, and high rep rate will provide strong benefits for assessed applications**
  - Quantitative simulations detail source needs
  - Simulations are being finalized and reported
- **Selectable energy (1 – 15 MeV) at moderate 10-50% energy spread**
  - Lower radiography dose, higher materials contrast
  - High photofission yield without interfering activation
- **Energy spread ≤ 2% enables NRF in treaty verification, cargo screening**
  - ΔE_γ ~<0.1 would enable nuclear materials assay (safeguards)
- **Narrow 'pencil' beam (~mrad divergence) a strong benefit:**
  - Scatter rejection in radiography, higher contrast & lower doses
  - Transmission measurements on massive objects, e.g. dry-storage casks
  - Pixel-by-pixel dose adaptation in radiography
  - High flux on target for strong photofission signature
- **Flux range 10^9-10^{12} photons/sec, rep rate range kHz to 10s of kHz**
- **Additional signatures (e.g. backscatter) identified, could increase impact**

Additional Studies

- **Localization of shielding volume essential for demonstrating absence of SNM in single-sided inspection scenarios**
  - No detectable fission signature is not sufficient
  - Backscatter imaging appears workable with pulsed MPS
- **MPS-enabled fissile-fertile discrimination techniques**
  - Polarized photofission: specific, and requires less stringent MPS energy spread than NRF
- **Low-Z material identification for contraband/explosive detection:**
  - NRF or photoneutron techniques
- **3D resolution of objects within complex structures (e.g. cargo)**
  - Voxelization & backscatter applicable – MPS reduces dose
- **High resolution tomography**
  - Enabled by MPS with micron-scale photon emission spot size
  - Potential for improved imaging of warheads for stockpile stewardship and intrinsic unique identification for treaty verification