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Title: Status of Fukushima Muon Tomography Project

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Intended for: Meeting with TEPCO personnel at LANL

Status of Fukushima Muon Tomography Project

LANL/TEPCO Meeting

Los Alamos, NM USA

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Outline

- **Previous developments**
  - Concept demonstration
  - Simulation
  - TEPCO-LANL Fukushima radiation measurements
- **Recent developments**
  - Material identification analysis
  - 3-d visualization
  - LANL-CC2 agreement
  - Simulation
- **Future developments**
  - Imaging small reactor
  - Site engineering and operations ("small fuku")
  - New FPGA code to purify data read-out

LANL has been working on reactor muon imaging since April, 2011.

- **April, 2011**
  - First version of reactor muon imaging proposal
  - Communications with Japanese scientists and government officials
- **August, 2011**

LANL

  - Demonstration experiment shows muon tomography imaging of reactors possible
  - Confirmed by simulation models
- **February, 2012**

DOE

  - Washington, DC muon imaging workshop
- **May, 2012**
  - Tsukuba, Japan muon imaging workshop

DOE

  - TEPCO-LANL measurements at reactor site
- **August, 2012**

LANL

  - Los Alamos, NM, TEPCO-LANL workshop

CC2

Recent LANL work has answered critical questions.

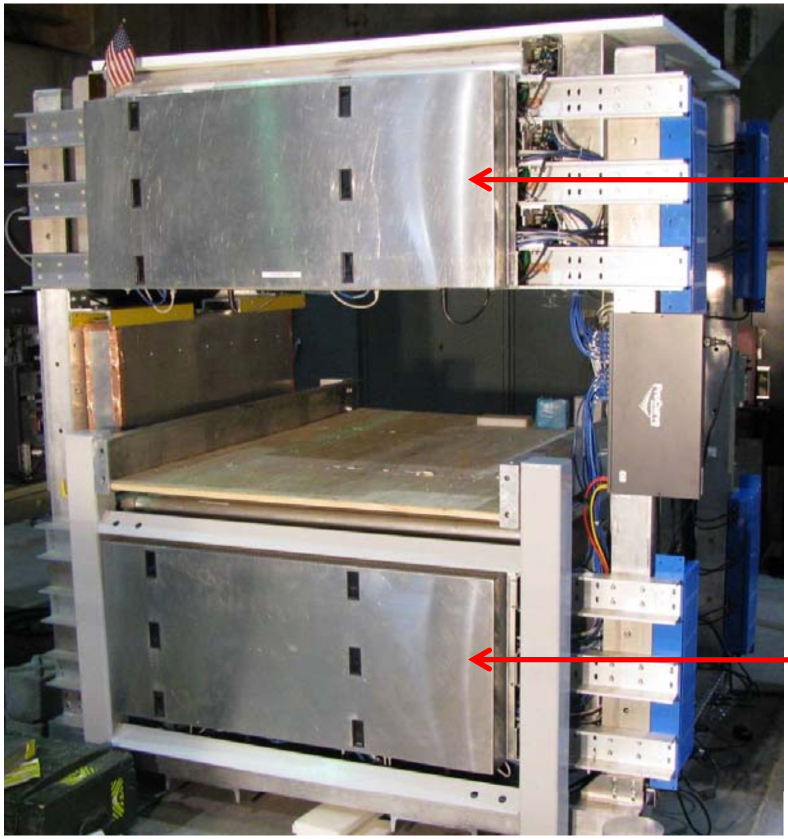
- **Combining muon scattering and transmission analysis improves material identification**
  - Analyzing LANL data for both muon transmission and scattering shows amount and location of each kind of material: fuel, concrete, steel, water, etc.
  - Demonstration measurement completed
    - Paper submitted to physics journal.
  - Muon analysis could provide guidance for fuel extraction.
- **GEANT4 simulation shows images of melted fuel**
  - Simulations performed for fuel-condition scenarios suggested by Sugawara, *et al*.
  - Muon tomography analysis shows good detail of fuel location.

LANL demonstration apparatus approximated the Fukushima Daiichi reactor configuration.

- Shielding
  - Concrete blocks (~2.7 m) similar to 3-m reactor containment shielding
- Targets
  - 70-cm of Pb (~ 126 L_{rad}) equivalent to ~ 2.8-m thick reactor fuel (~ 124 L_{rad})
  - Several tons of Pb bricks in various shapes
  - Approximation to melted masses of uranium in reactor
- Detectors (5-cm-diameter aluminum drift tubes, sealed, filled with gas)
  - Placement and size approximated possible Fukushima deployment:
    - Demonstration: ~7-m separation , 1.2-m x 1.2-m detector (~1.4-m^2)
    - Fukushima: ~50-m separation, 8.4-m x 8.4-m detector (~70.6-m^2)
  - Angular acceptance: between 11^o and 26^o above horizon
  - Decision Sciences Corporation can manufacture complete system
    - Drift tubes (can make ~ 300 per day per shift)
    - Electronics
    - Software (data acquisition, online processing, real time reconstruction)

The experiment used previously constructed detectors.

- **Two sets of trackers (MMT – Muon Mini-Tracker)**
- **Each tracker set has 3 x-y pairs planes, for a 6-fold tracking coincidence, in and out.**
- **Tracker sets moved to “mock reactor”.**
- **One set placed high on shielding, to track incoming muons.**
- **Other set placed low on the “exit” side of the shielding.**

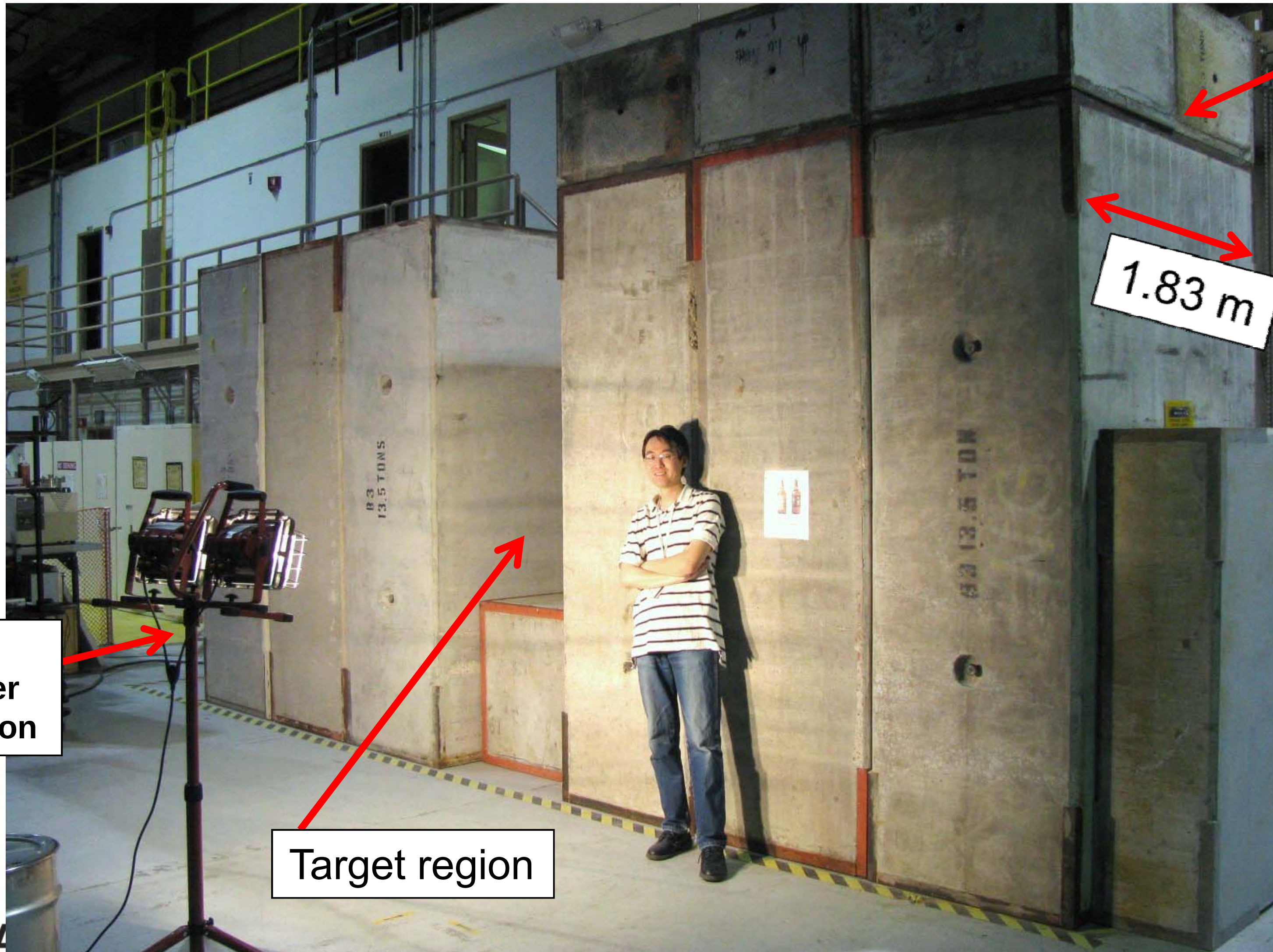


Tracker set 1

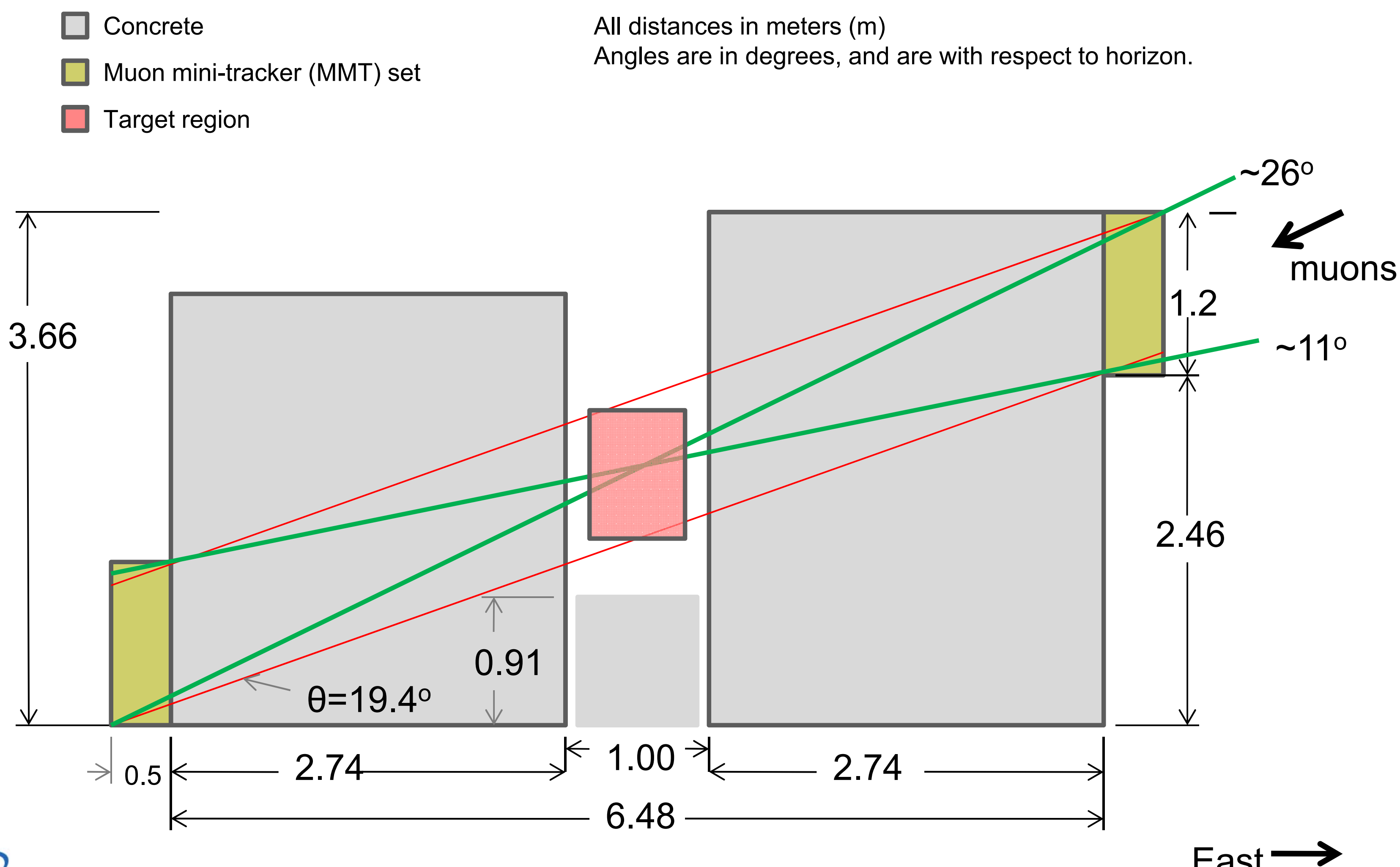
Tracker set 2

~ 1.2 m

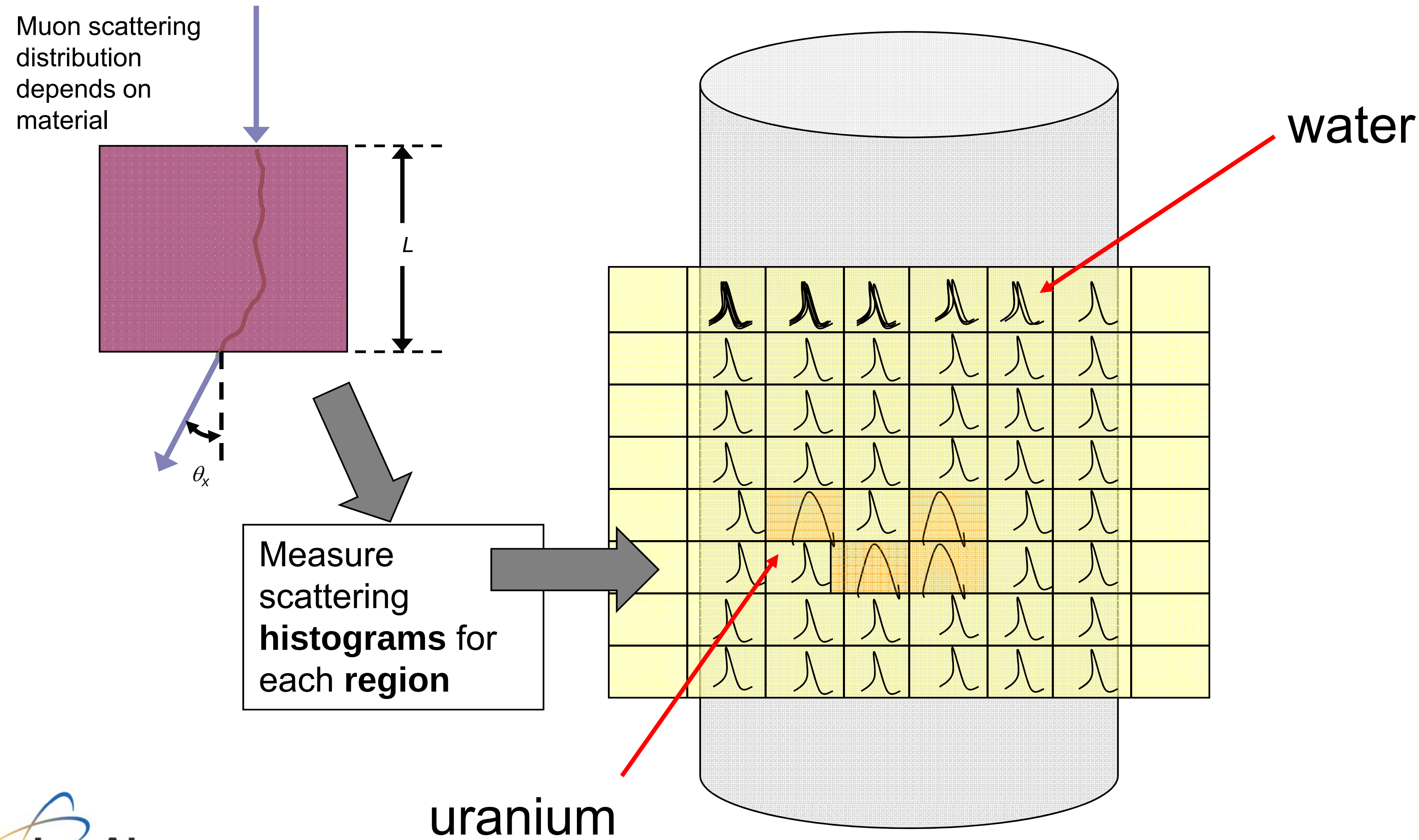
Concrete shielding thickness was similar to reactor containment shielding.



The demonstration apparatus approximated the cross section of a reactor.

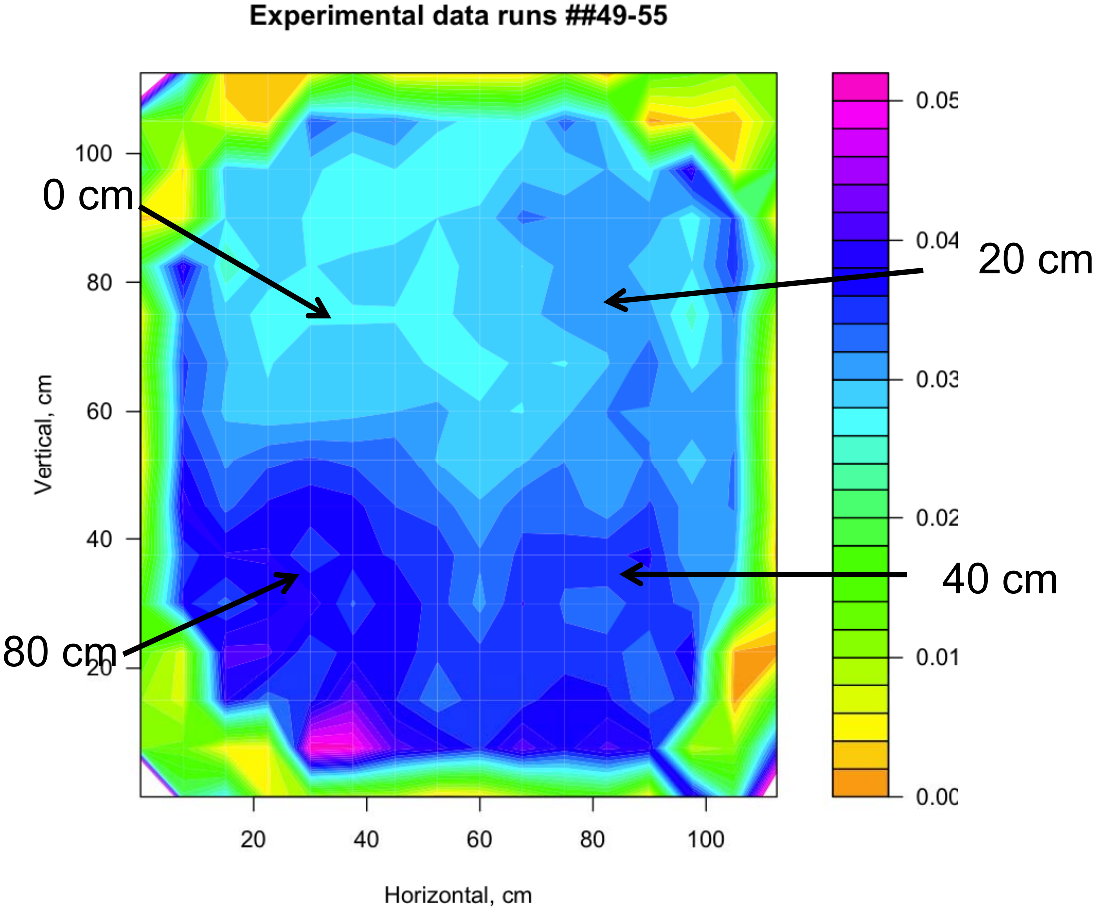


The multiple scattering distribution is wider for high-Z objects; muon scattering distribution shows material composition.



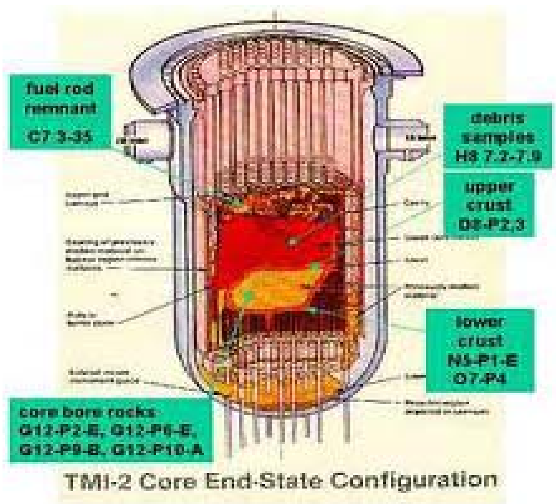
A target of 80-, 40-, and 20-cm of lead (Pb) was imaged.

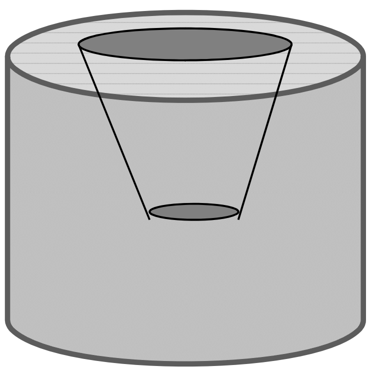
- 210 hours of data

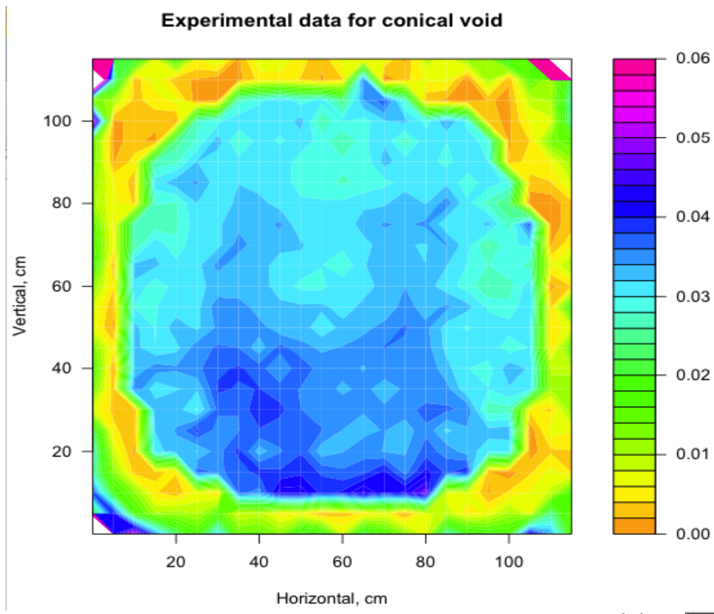


An 80-cm-thick Pb target, with “conical void” was imaged – an attempt to approximate TMI core.

- 4.5 tons of Pb
- 500 hours data (20 days)







LANL continues working on critical issues.

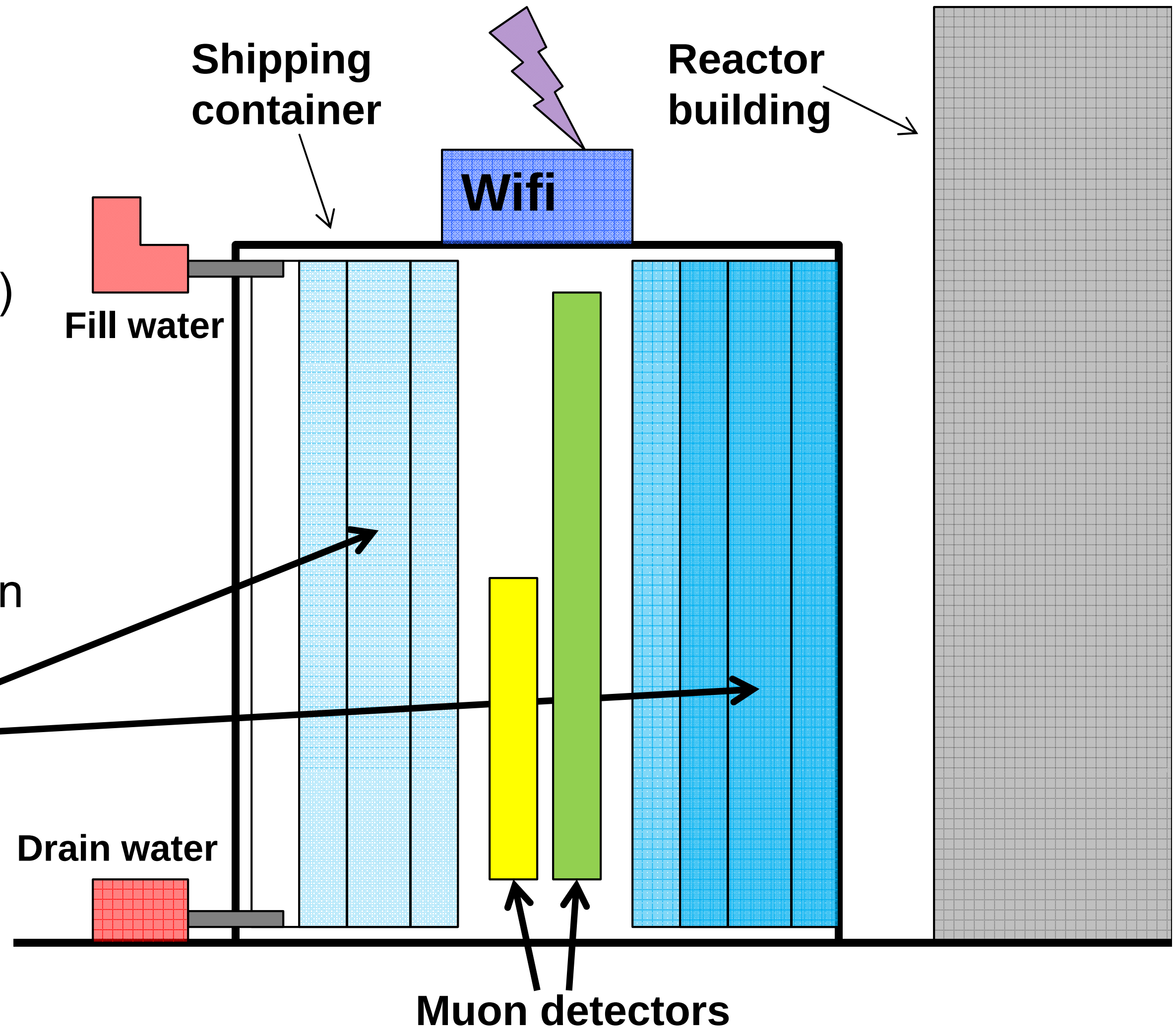
- **Muon mini-tracker (MMT) will be used to image small reactor**
  - Collaboration with University of New Mexico (Albuquerque) Dept. of Nuclear Engineering. Will measure image of reactor structure.
  - Uranium powder core, low power
  - Radiation environment similar to Fukushima Daiichi – good test of system.
- **Proposing engineering and operations systems test at Fukushima site**
  - Determine detector shielding requirements.
  - Operate at site – electronics, data acquisition, experiment control.
  - Demonstration system operations at Fukushima site
- **Test efficiency of FPGA firmware signal coincidence**
  - New FPGA code – standard technique for high-rate experiments
  - Track coincidence to lower single-hit radiation background rate and data read-out
  - Test at LANL

Engineering tests will reduce or eliminate project risks.

- **Muon tomography is a mature technology deployed in shipping ports**
  - Robust system – operates outdoors.
  - Fukushima Daiichi site is harsher – radiation and clean-up site
  - Demonstrating solutions to operating in harsh conditions will lowering risk.
- **Engineering test components and assumptions:**
  - Detector system components will be purchased from vendors
  - System will be assembled and tested at LANL
  - TEPCO personnel will be trained on system installation and operation at LANL
  - Complete apparatus will be shipped from US to J-Village (site of final preparations)
  - System will be installed and operated at FD by TEPCO with LANL assistance
  - Data collection and remote operations via wireless connection, and transmission of data to LANL computers in US. LANL scientists do not have to be at FD during measurement
  - Data analysis performed in US by LANL team
  - Decontamination and removal of system from FD will be done by TEPCO

Test can be deployed quickly in container.

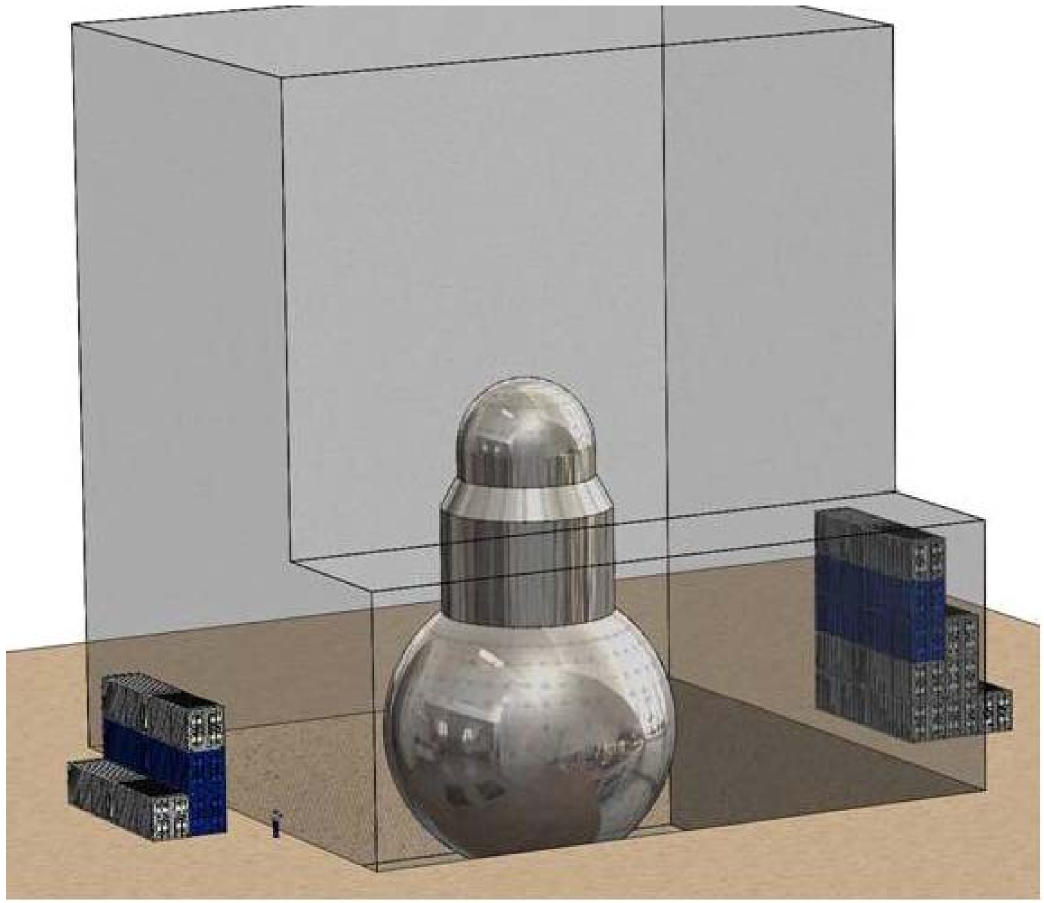
- **Radiation**
  - Shield thickness
  - Radiation safety
  - Detectors (singles rate)
  - Electronics
- **Demonstrate Solution**
  - Remote operation
  - Remote Data Collection
  - Tracking efficiency as function of shield thickness



Specifc risk reductions can be anticipated.

- **Risks: $, ¥, delays, operations, impaired measurement**
  - Unanticipated problems ALWAYS arise
- **Shielding study**
  - Optimize shielding design for the full imaging measurement
- **Wireless data collection**
  - Show wireless and GPS systems can operate in FD site environment.
- **Electric power**
  - Operational data and experience guiding robust system design
- **Redundancy for avoiding system failure**
  - Select redundancy features
  - Exercise recovery mode
- **System installation and operations**
  - Designs and procedures minimize personnel radiation exposure associated with installation and operations.

Test occupies smaller space than full deployment – on both sides.



Muon scattering can provide best images of reactor fuel.

- **Thick targets imaged inside very thick concrete shield**
  - 2.7-m of concrete – similar to Boiling Water Reactor (BWR)
  - 80-cm of Pb – similar to areal-density thickness of reactor fuel
  - ~ months to image each target
- **Scale-up to reactor**
  - Detectors would be at building exterior, ~50 m apart
  - Maintain ~ same solid angle with detectors 5-m x 10-m (commercially available)
  - Measure image showing location of fuel
  - Reactor "view" depends on location of detectors
    - Similar to LANL demonstration – view of reactor pressure vessel (RPV)
    - Installed below ground – view of lower reactor containment

LANL, US DOE, and CC2 funds have supported our work.

- **LANL funding**
  - Demonstration measurement – completed (September, 2011)
  - TEPCO-LANL workshop
  - Small reactor imaging
- **DOE funding for**
  - Japan-US Workshop, Washington, DC, 15-16 February, 2012
  - Japan-US Workshop, KEK, Japan, 23-25 May, 2012
- **CC2 Investor funds**
  - TEPCO-LANL workshop
  - Proposal preparation
- **Need TEPCO/METI funding for:**
  - Engineering and operations tests at Fukushima reactor
  - Engineering studies of shielding, support, installation, operations, etc.
  - Image cores of Fukushima reactors