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

- **February, 2012**
  - Washington, DC muon imaging workshop

- **May, 2012**
  - Tsukuba, Japan muon imaging workshop
  - TEPCO-LANL measurements at reactor site

- **August, 2012**
  - Los Alamos, NM, TEPCO-LANL workshop
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-m²)
    - Fukushima: ~50-m separation, 8.4-m x 8.4-m detector (~70.6-m²)
  - Angular acceptance: between 11° and 26° 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.
Concrete shielding thickness was similar to reactor containment shielding.
The demonstration apparatus approximated the cross section of a reactor.

Concrete
Muon mini-tracker (MMT) set
Target region

All distances in meters (m)
Angles are in degrees, and are with respect to horizon.
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
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

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Specific 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**

- **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