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Title: Our Next Two Steps for Fukushima Daiichi Muon Tomography

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Report

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Our Next Two Steps

for

Fukushima Daiichi Muon Tomography

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Abstract

After the vast disasters caused by the great earthquake and tsunami in eastern Japan, we proposed applying our Muon Tomography (MT) technique to help and improve the emergency situation at Fukushima Daiichi using cosmic-ray muons. A reactor-tomography team was formed at LANL which was supported by the Laboratory as a response to a request by the former Japanese Prime Minister, Naoto Kan. Our goal is to help the Japanese people and support remediation of the reactors.

At LANL, we have carried out a proof-of-principle technical demonstration and simulation studies that established the feasibility of MT to image a reactor core. This proposal covers the next two critical steps for Fukushima Daiichi Muon Imaging: (1) undertake case study mock-up experiments of Fukushima Daiichi, and (2) system optimization. We requested funding to the US and Japanese government to assess damage of reactors at Fukushima Daiichi. The two steps will bring our project to the "*ready-to-go*" level.

1. Case Studies

The previous reactor mock-up tests were completed at LANL to prove the principle of "reactor tomography" to image a mock reactor core through thick concrete walls. In the demonstration, we measured cosmic-ray muons passing through a physical arrangement of material similar to a nuclear reactor, with thick concrete shielding and a heavy metal core (*fig.1*). At boiling-water reactors (BWR) of the type installed at the Fukushima Daiichi plant, the concrete and steel shielding of the primary containment is about 3 m and 0.4 m (total thickness). Our mockup reactor has a 5.5-m concrete wall, which gives similar mass-length to the reactors. The trajectories of cosmic-ray muons were measured with two tracking detectors composed of gas-filled ionization drift tubes. We used our "Mini Muon Tracker" (MMT) that had multiple pairs of *x*-*y* planes in each of two tracking modules.

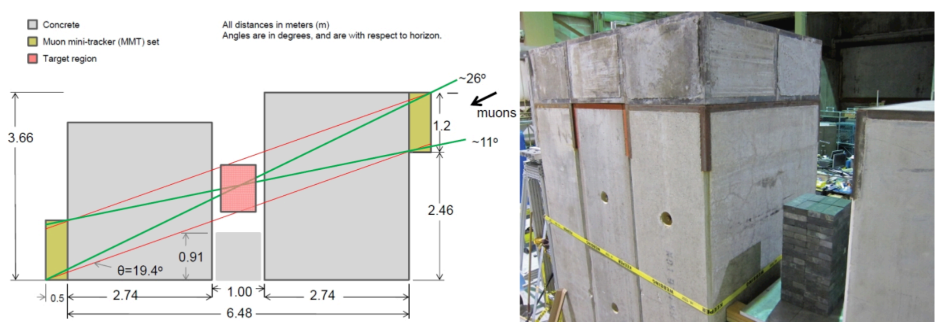

Figure 1: Schematic drawing of demonstration experiment using reactor mock up (left), and the photo (right).

We studied several target arrangements for specific features using the technique described above. The target arrangements consisted of the following: no target/empty, lead with a conical void, lead quadrants of varying height, a lead resolution column, and a lead and iron contrast column.

Each target volume corresponded to a particularly useful scenario to study. The conical-void target was similar in shape to the melted core of the Three Mile Island reactor. The lead quadrants were imaged to demonstrate differentiation capabilities between varying thicknesses. The lead resolution column was optimal for determining spatial resolution. Finally, the contrast column was used to measure the limits in differentiating between fuel and the reactor pressure vessel (RPV). Each scenario ran for approximately 1 week yielding statistics on the order of $\sim 2\times 10^4$ events. Some of the analyzed results are shown in *fig.2* and *3*.

Figure 2: Schematic drawing of conic-void demonstration (left), and the photo (center). The void was successfully observed (right) through two 3-m concrete walls.

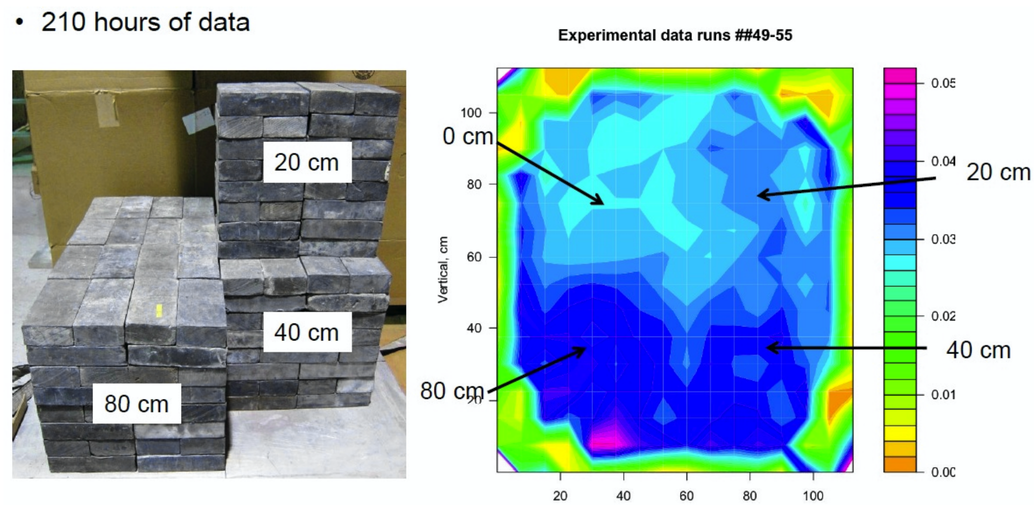

Figure 3: Photo of the demonstration (left). Lead targets of 20-, 40- and 80-cm thickness were imaged through concrete wall of 6-m thickness (right).

For the next step, we propose to work on following demonstrations:

1. Detection of small high-Z materials with good estimation of their amount. In the case of Three Mile Island, the sizes of the debris were ~45 cm. This test will give us the minimum size of the debris that we can detect.
2. Detection of high-Z materials surrounded by water. This is actually the case expected at Fukushima Daiichi where melted nuclear fuel is in the water.
3. A long run to accumulate statistics for 2-months. This would provide us with good data to improve the analysis algorithms.

These experiments will demonstrate the ability of MT to detect melted uranium fuel at Fukushima Daiichi, and would provide convincing results to TEPCO, the Japanese government, and the US government.

Using the currently available MMT, *phase 1* will be completed in 3 months after the initiation of the funding. A cost estimate is shown in *Table 1*.

Table 1: Cost estimate for phase 1.

Items	Thousand USD
Mechanical supports for Mini Muon Tracker	25
MMT installation	10
Change configurations	10
Detector test / calibration	5
Measurement	10
Analysis	100
Simulation study	25
Material and Supply	15
Total	200

2. System Optimization

During *phase 1*, we propose to work on following system-optimization studies:

1. Develop new electronics and data-acquisition system that can handle the expected high background rate of Fukushima Daiichi.
2. Develop a small-scale detector. Test system operation under high background rate at Fukushima Daiichi.
3. Purchase Giant Muon Tracker (GMT) from Decision Sciences Corp. (DSIC). The GMT was designed and manufactured at LANL but it is currently owned by DSIC. The GMT can be considered as a prototype version of the eventual Fukushima Muon Tracker (FMT).

The purpose of *phase 2* is to upgrade the technical level of the project to a *ready-to-go* level. We have carried out previous system studies, and the lessons from those previous studies will be implemented with solid engineering solutions.

The Fukushima Daiichi site has high radiation level up to several mSv/h. Under a high radiation background, random coincidences of detectors produce accidental events. The high data rate caused by the radiation background also puts a burden on the data-acquisition system. To cope with the background, we will redesign our electronics boards so that they have increased capabilities to analyze the additional events, and compress the data before they are transported to data-acquisition computers. An upgrade of the electronics will allow the detector operation under a radiation environment of 4-mSv/h level. We will test the new system at the high-radiation environment at LANL.

We will also develop a small detector setup and install it at Fukushima Daiichi site to test its operation under high radiation background. Another goal of this small detector is to demonstrate remote operation at Fukushima Daiichi because the access to the detector is not easy during the main project.

Designing a radiation shield that can be installed at Fukushima Daiichi in a short time is also challenging. Our proposed setup at Reactor #1 is shown in *fig.4*. The radiation shield provides a mechanical support to the muon tracker, and the shield must have earthquake-resistant structures that meet Japanese standards. Our preliminary design of the shield was created in collaboration with a Japanese construction company. The design is shown in *fig.5*. We will send two Japanese-speaking personnel to Japan to work with the construction company to finalize the design. The installation procedure will be supervised by TEPCO.

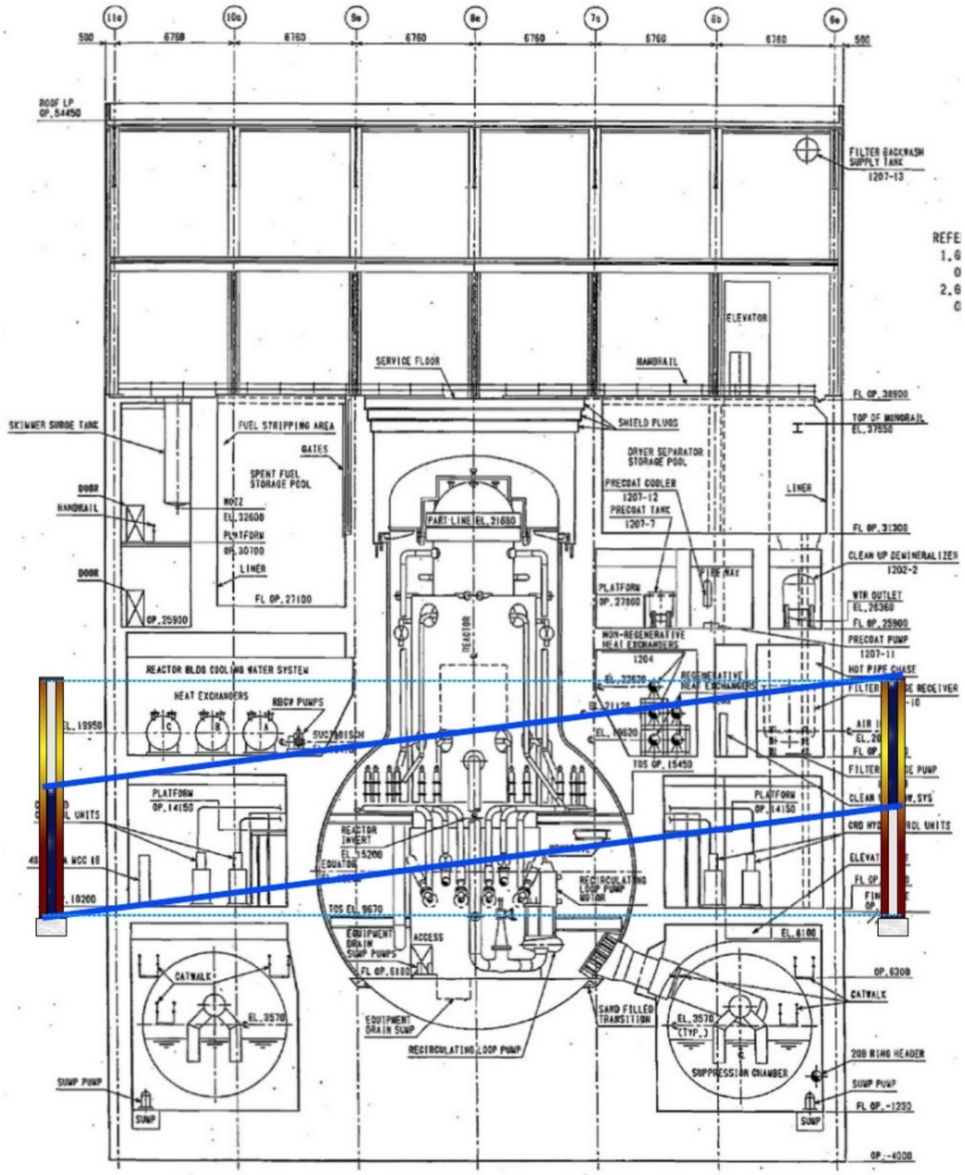

Figure 4: Proposed detector setup at Fukushima Daiichi. Two muon trackers will be installed near the wall of the reactor building. The two muon trackers would be ~50-m apart.

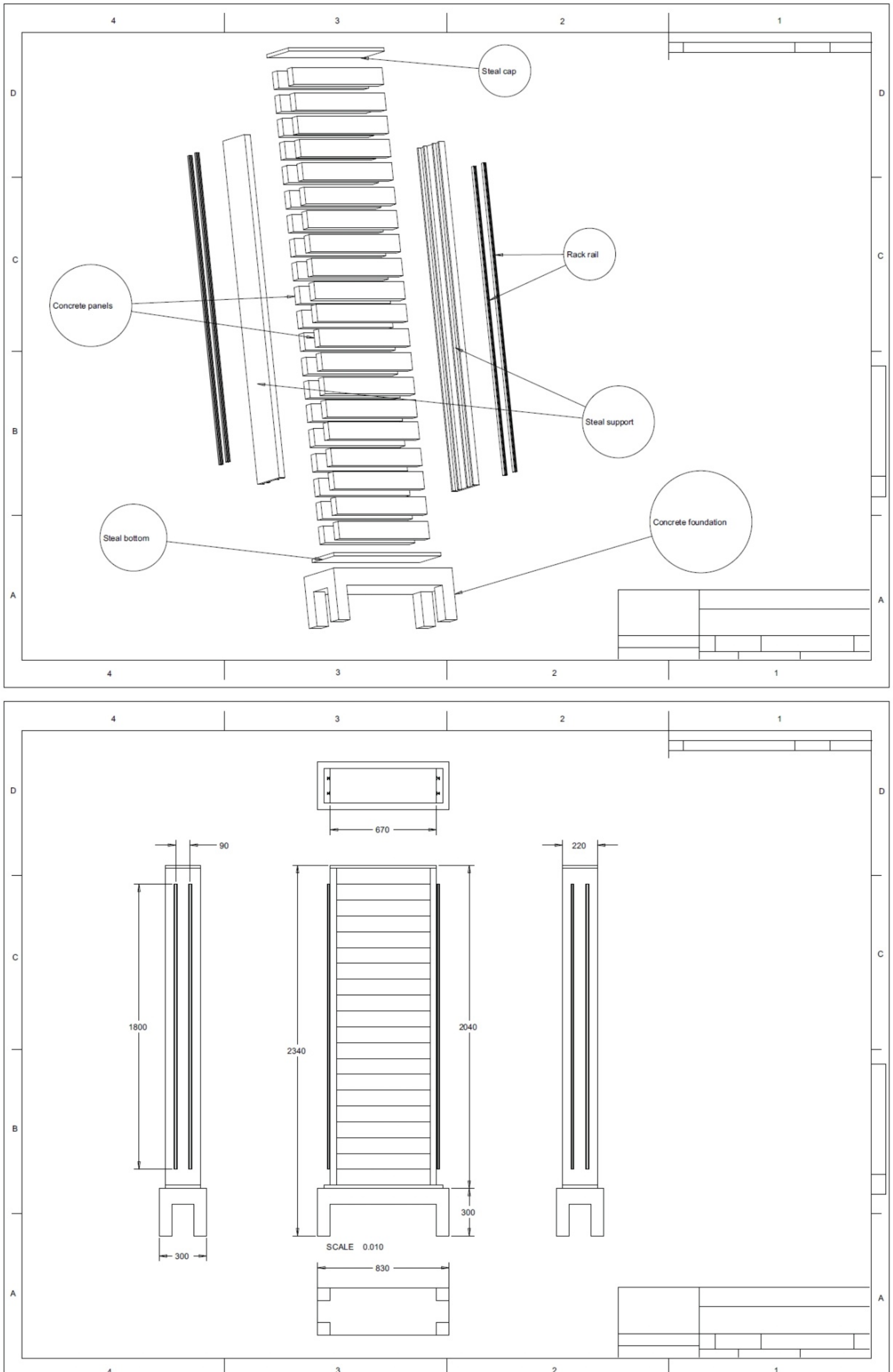

Figure 5: Engineering drawing of BUKU shield. It would take 2 days to construct the shield at Fukushima Daiichi, if all the equipment is provided/available.

In the past, we manufactured Giant Muon Tracker (GMT) at LANL, which is similar to proposed FMT. GMT is transferred to and owned by DSC. Recently we were informed that we could buy GMT back from DSC at a deeply discounted price so that we could use it as a test machine of FMT. Having GMT at LANL will help the project because we can test new software and algorithms before we implement them on FMT.

The proposed *phase 2* covers all the remaining engineering studies for the Fukushima Daiichi Muon Tomography project. A cost estimate for *phase 2* is shown in *Table 2*.

Table 2: Cost estimate for phase 2.

Items	thousand USD
R&D on electronics / manufacture FPGA boards	300
R&D on small detector for radiation test	100
Manufacture small detector	125
Radiation tests at LANL	10
Radiation tests at Fukushima Daiichi	25
Data analysis	50
R&D on data-acquisition system	50
Planning installation of FMT	30
Purchase GMT	300
Material and supply	10
Total	1,000

We have been communicating with Japanese government and US Department of Energy. Progress of *phase 1* and *2* will be reported to them. After *phase 2*, we expect an official request from the Japanese government to the US to start our project at Fukushima Daiichi.

We requested the Fukushima Daiichi Muon Tomography project to be supported by the Japanese government and the US government at an equal level as shown in *Tables 3* and *4*. The funding from Japan will cover the equipment such as muon trackers, the radiation shield, and their mechanical supports. Because they are likely to get radioactively contaminated at Fukushima Daiichi, we consider it is appropriate for Japan to own this equipment. The Japanese share also includes costs to install muon trackers at Fukushima Daiichi and site support during the measurements. The funding from the US will cover support for the LANL team, simulation work, data-acquisition system development, and data analysis.

Table 3: Requested funding to Japanese government.

Items	Thousand USD
Fukushima Muon Tracker	2,500
Radiation shields	1,000
Supports at Fukushima Daiichi site	500
Total	4,000

Table 4: Requested funding to US government.

Items	Thousand USD
Supports for LANL staff	3,000
Simulation studies on supercomputer	200
Data acquisition system	100
Data analysis	200
Travel	200
Material and supply	300
Total	4,000

We note that, imaging and visualization of the nuclear fuel assembly can be valuable for operating the nuclear-power plant. Though it outsides the scope of the project, we will demonstrate a capability of MT to provide additional peace of mind for daily operation of a reactor. Our MT has a possibility to be installed to any reactor site in the world. If MT were installed in the facility in an optimized fashion, inside the building, closer to the core, it could provide a near real time monitoring of the reactor core.