

## PROPOSED FACILITY LAYOUT FOR MARIE\*

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### *Abstract*

The MaRIE (Matter-Radiation Interactions in Extremes) experimental facility will be used to advance materials science by providing the tools scientists need to develop materials that will perform predictably and on demand for currently unattainable lifetimes in extreme environments. The Multi-Probe Diagnostic Hall (MPDH) will create probes of matter using both photon- and proton-based diagnostics. The Fission and Fusion Materials Facility ( $F^3$ ) will provide capabilities for materials irradiation studies, subjecting materials to radiation extremes that are present in fission and fusion environments. The Making, Measuring, and Modeling Materials (M4) Facility will foster discovery by design of next-generation materials that will perform with better durability in extreme environments. MaRIE features a 20-GeV electron linac for an X-ray driver. Five X-ray beams will be delivered to the experimental areas. The facility will also deliver an electron beam to MPDH. The existing LANSCE proton beam will be delivered to MPDH and  $F^3$  in addition to the existing LANSCE areas. Multiple high power lasers will deliver beams to MPDH. This paper will provide an overview of the MaRIE facility layout.

### MARIE

The MaRIE (Matter-Radiation Interactions in Extremes) experimental facility will be used to advance materials science by providing the tools scientists need to develop materials that will perform predictably and on demand for currently unattainable lifetimes in extreme environments. This facility is undergoing pre-conceptual design. It will be a significant enhancement to the existing LANSCE facilities at the Los Alamos National Laboratory, Los Alamos, NM. The proposed facility layout, illustrated in Fig. 1, is evolving as the pre-conceptual design matures.

### MARIE FACILITIES

MaRIE has four major facilities, (1) The Multi-Probe Diagnostic Hall, (2) the Fusion, Fission Material Facility, (3) the Making, Measuring, and Modeling Materials Facility, and (4) the Free Electron Laser Facility.

#### *Multi-Probe Diagnostic Hall (MPDH)*

MPDH will provide unprecedented probes of matter under dynamic extremes including, for the first time, simultaneous x-ray scattering and charged particle imaging measurements of materials interactions at relevant temporal, spatial, and spectral resolutions. These

tools will advance the frontiers of dynamic materials behavior spanning solidification phenomena to turbulence in warm dense matter.

#### *Fusion Fission materials Facility ( $F^3$ )*

$F^3$  will provide much needed environments for materials irradiation studies, and even more importantly, will define the frontiers of radiation damage science by advancing the field from post-irradiation materials qualification to in situ diagnostics, thereby providing the ability to better understand and control radiation damage.

#### *Making, Measuring, and Modeling Materials Facility (M4)*

M4 will enable the discovery-by-design of materials to perform with orders-of-magnitude better durability in these extreme environments. Researchers at M4 will also discover the next generation of integrated solid-state solutions for renewable energy and radiation detection. Translating new quantum and nanoscale discoveries to realization for practical applications requires the same capability to bridge the gap from atomic-scale understanding to device performance as that required to understand and exploit the limits of materials strength and irradiation resistance.

#### *Free Electron Laser*

The preferred alternative for the light source for MaRIE is a very-hard-x-ray (50 keV) high peak, low average brightness XFEL. Free electron lasers are based on technology originally developed at Los Alamos and elsewhere in the 1980s and 1990s. Highly relativistic and energetic pulses of electrons are injected into an undulator, a device with a periodically varying magnetic field. Unlike a usual ring light source where the electrons individually wiggle and emit radiation, in a free electron laser the electrons emit radiation but then coherently interact with those photons and non-linearly bunch up. The bunches then radiate together, causing the total number of photons from a bunch to be proportional to the square of the number of electrons (hence the brilliance) with all the photons being emitted in phase (coherency). One technological challenge is reducing the transverse electron velocity in the pulse—the angular spread in velocity phase space known as the emittance of the beam. For MaRIE, another major challenge will be to reduce the bandwidth of the emission, i.e., to make the photons more monoenergetic, and hence, make the photons also be coherent in time along the pulse.

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Figure 1: The MaRIE Facility Layout evolves as the design matures.

## BEAM DEPLOYMENT & THE PROPOSED FACILITY LAYOUT

MaRIE must fit on the mesa and this drives the overall site layout and in turn the technical requirements on major components, for example the XFEL. The XFEL is positioned to start at the end of the mesa and is followed by the switchyard, undulators & wigglers, and the XFEL transport lines.

MaRIE has a number of probe beam types deployed to the MaRIE experimental facilities (Table 1). Five 50 KeV coherent x-ray XFEL beams are delivered; two to the two F<sup>3</sup> locations, two to the two MPDH halls, and one to the M4 Hard X-ray experimental room. Incoherent x-ray beams of the appropriate energy, 10, 50, 100, or 400 KeV as selected for the experiment, are delivered to the two F<sup>3</sup> locations and one is delivered to the M4 soft x-ray experimental room. E-beams for electron radiography (e-RAD) are delivered to each of the two MPDH halls. Each of the two MPDH halls and the Ex-situ F<sup>3</sup> location have proton beams delivered for proton radiography (PRAD). M4 also has an ion beam facility.

The two 100m long detector tunnels for F<sup>3</sup> cause F<sup>3</sup> to be located 35 feet below the existing Area-A floor so that they can pass below existing accelerator facilities. Driven by the need for F<sup>3</sup> to be located 35 feet below the existing Area-A floor and the topology of the mesa, the beamline tunnels are located underground starting in the area of the beam switchyard.

Detectors are located at different distances from the center of the sample locations according to their needs.

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For the XFEL beams detectors are located 100m from the sample location. For the incoherent x-ray beams detectors are located at 5 and 10m from the sample location depending on the energy level of the beam being used.

The XFEL undulators have an associated Undulator Laboratory for their assembly, inspection, and maintenance. A gallery extends from the Undulator Laboratory out over the undulator tunnels so that undulator assemblies can be transported between these locations.

## CONCLUSION

Success in conquering the micron frontier requires more than the ability to make measurements on the scale of 10-6 meters, a challenge routinely met by a large suite of microscopies and measurement techniques. Success requires simultaneous, in situ, time-resolved measurements of dynamic (rapidly evolving in time) and stochastic (random) processes, especially in extreme environments on the scale of the microstructure. To predict the behavior of complex, multigranular materials undergoing exposure to high radiation or subjected to high rates of strain (for example, structural materials in fission and fusion reactors), researchers need to know both where the atoms are located and where they are not—that is, knowing precisely void size and location inside a three-dimensional, macroscopic solid as a function of time with nanosecond to picosecond resolution.

Table 1: Beam Deployment

Beam Type & ENERGY (KeV)		e-Beam	PRAD	Ion Beam Facility	Main P-Beam	Omega-EP like 3 Lasers
1.5	50	10	50	100	400	
<b>Location</b>						
<b>F3</b>						
In-situ	X	X	X	X	X	
Ex-situ	X	X	X	X	X	
<b>MPDH</b>						
EH-1 (north)	X					X
EH-1 Laser Only Area						X
EH-2 (south)	X					X
EH-2 Laser Only Area						X
<b>M4</b>						
HARD XRAY	X					
SOFT XRAY	X					

Distance To Detectors  
(Meters)

100	10	10	5	5
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50 KeV X-Ray spread 7-degree total included angle from test point to detectors.  
For M4 Variable Energy X-Ray Beams:  
Hard X-RAY 20 to 50 KeV  
Soft X-RAY 0.5 to 1.5 KeV

The advanced experimental tools needed to perform such measurements, including coherent, hard x-ray sources and high-intensity, high-energy proton beams, are just now becoming available. Techniques such as coherent x-ray diffractive imaging and proton microscopy promise a revolution in our ability to predict and control materials functionality. Just as first-generation x-ray free electron lasers (XFELs) are allowing us to watch chemical bonds break and form, these next-generation x-ray sources will catch complex materials in action. Building on the demonstrated success of proton radiography, which was developed at Los Alamos for revealing macroscopic materials dynamic phenomena, proton microscopy is uniquely suited to image micron-scale void formation and evolution within the volumes of dense materials.

The availability of advanced diagnostic tools is one

reason why now is the time for MaRIE. Advances in multiscale modeling and high performance computing (at the peta- [10<sup>15</sup>] and exa- [10<sup>18</sup>] flop scale) are another. For the first time accurate first-principles simulation of microstructure and radiation damage evolution at relevant time and length scales is possible. The ability to validate (or invalidate) these models is a key requirement for predictive understanding of materials functionality.

**REFERENCES**

[1] “MaRIE: Matter-Radiation Interactions in Extremes,” Experimental Physical Sciences VISTAS, Fall 2010, LALP-10-059.