DISCLAIMER

Cooperative Research and Development Agreement (CRADA) Final Report

Report Date:
9/26/2025

Sahar Iranipour, resource analyst, is submitting the CRADA report on behalf of PI Corinne Layland -Bachmann, who is no longer at the lab.

In accordance with Requirements set forth in the terms of the CRADA, this document is the CRADA Final Report, including a list of Subject Inventions. It is to be forwarded to the DOE Office of Scientific and Technical Information upon completion or termination of the CRADA, as part of the commitment to the public to demonstrate results of federally funded research.
Parties to the Agreement: Nanometrics Inc, Lawrence Livermore National Security LLC, and Lawrence Berkeley National Lab

CRADA number: TC02344

CRADA Title: Operational Forecasting of Induced Seismicity

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Sponsoring DOE Program Office(s):
Fossil Energy

LBNL Report Number:
LBNL-2001710

OSTI#: 2997177

Joint Work Statement Funding Table showing DOE funding commitment:

DOE Funding to LBNL	$176,150
DOE Funding to LLNS	$195,690
Participant Funding to LBNL	0
Participant In-Kind Contribution Value	$22,444

Total of all Contributions	$394,284

Provide a list of publications, conference papers, or other public releases of results, developed under this CRADA:

(Publications must include journal name, volume, issue, Digital Object Identifier)

N/A

Provide a detailed list of all subject inventions, to include patent applications, copyrights, and trademarks:

(Patents and patent applications are to include the title and inventor(s) names. When copyright is asserted, the Government license should be included on the cover page of the Final Report)

No Subject inventions
copyright activity - Activity CP02650 – ORION, v0.5 (Operational Forecasting of Induced Seismicity)

Executive Summary of CRADA Work:

This was a collaborative effort between Lawrence Livermore National Security, LLC ("LLNS"), as manager and operator of Lawrence Livermore National Laboratory ("LLNL"), The Regents of the University of California, as manager and operator of Lawrence Berkeley National Laboratory (Collectively, Contractors) and Nanometrics, Inc. ("Participant"), to develop a toolkit called "Operational Forecasting of Induced Seismicity (ORION)" that includes a decision tree method for operational forecasting of induced seismicity rates related to fluid disposal operations.

Summary of Research Results:

The specific technical accomplishments related to the development of the python-based software
package called ORION are itemized below and depicted in Figure 1:

- Two physics-based forecasting methods,
- Statistical measures for the probability of exceedance of a target magnitude earthquake within a given time-period,
- Incorporation of open-source tools for estimating statistical properties of seismic catalogs and evaluation of the goodness-of-fit of output forecasts,
- Spatiotemporal estimates of the pressure associated with injection via the use of Theis equations,
- Spatiotemporal estimates of the number of seismic events related to that injection,
- Methodologies to ingest operational data and seismicity catalogs from and end-user,
- Methodologies to query operational or seismicity data from local public websites,
- Ingestion of results from machine-learning based methodologies for estimating the pressure distribution,
- Software documentation,
- Interactive graphical user interface that can be used by a wide variety of end-users.

At present, none of the statistical methodologies are currently implemented within the ORION toolkit. LBNL was tasked with developing the python-based coding package for these methods. Effort was contributed by LBNL and progress was made, however, the full extent of the work package was not completed. It is estimated about ~60% of the work is outstanding. Following the conclusion of this CRADA, LLNL will assume the responsibility for integrating the statistical methods into the ORION toolkit. Once completed, ORIONv0.5 will be released for open-source use.