SEISMIC MONITORING USING ARRAYS IN THE MIDDLE EAST

Rengin Gök[1], Moira L. Pyle[1], Issa El-Hussain[2], Abdullah Al-Amri[3], David Harris[4] and Douglas A. Dodge[1]

[1] Lawrence Livermore National Laboratory, USA
[2] Sultan Qaboos University, Sultanate of Oman
[3] King Saud University, Kingdom of Saudi Arabia
[4]Oregon DSP, USA

(T3.5-P39)

ABSTRACT

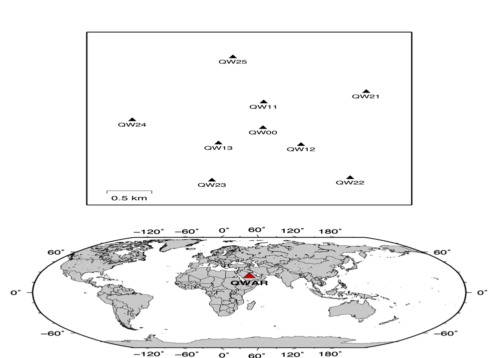
As part of capacity building and joint research under the U.S. Department of Energy's Seismic Cooperation Program (SCP), Lawrence Livermore National Laboratory (LLNL) collaboratively installed 9-element seismic arrays QWAR (Saudi Arabia, 2012) and HQAR (Oman, 2015). All elements are equipped with 3-component short-period sensors. HQAR array data is received in real-time at the Earthquake Monitoring Center (EMC) of Sultan Qaboos University (SQU) using Antelope software. The aperture of both arrays is approximately 3.5 kilometers, and minimum element spacing is about 500 meters. We test the array capabilities with a time-domain beampacking scheme which searches for the optimal slowness vector of a signal by measuring the power of beams formed over a grid of slowness points. The slowness vector provides information on both the apparent velocity and direction of the signal. We extend this analysis to examine the coherent noise recorded over time at the array. Coherent noise is generated globally at a range of frequencies and is useful due to its ability to impact an array's detection performance, and its ability to be used in a variety of seismic imaging studies. We also test waveform correlation detection performance using both arrays and Global Seismic Network data in the Middle East.

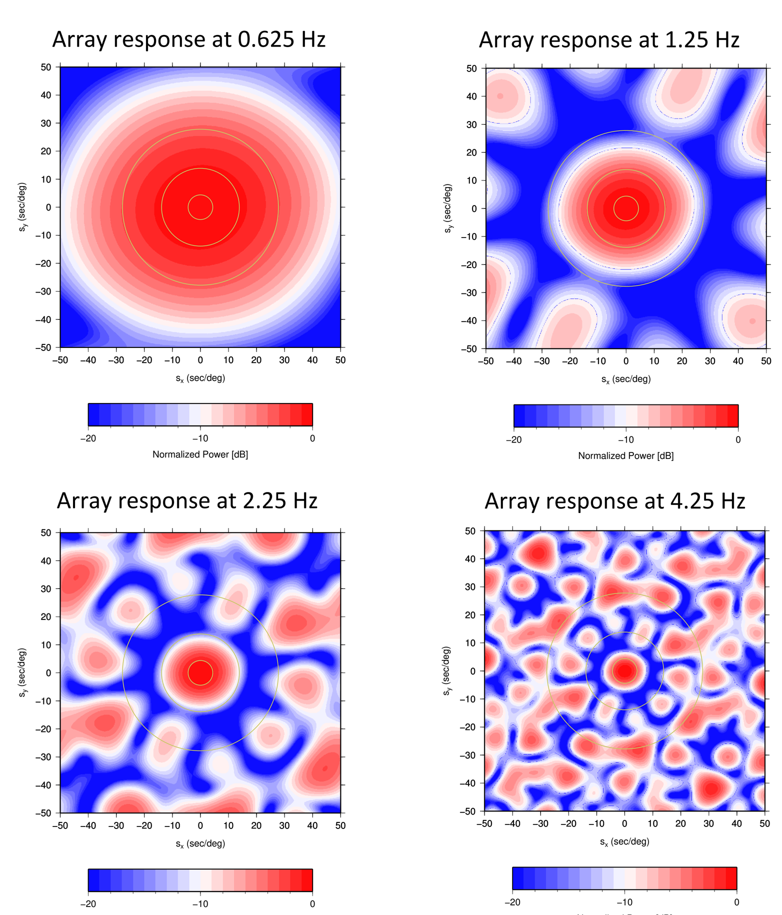
We collaborated with EMC experts on the installation of Oman's first seismic array.

HQAR is adjacent to the foothills of the Al Hajar Al Gharbi mountains, in an area where surface exposures of the Semail ophiolite allow installation of stations on bedrock with minimal relief. The vault is set in bedrock (ophiolite in this case) and has a tight-fitting steel cover with thermal isolation provided by a second plywood cover.

QWAR is located in Arabian Shield just west of the western outcrop of cover rocks. Each element is equipped with 3-Component SS-1 ranger short-period sensors and Q330 Kinematrics digitizers. Each station is a concrete vault approximately two meters square and two meters deep.

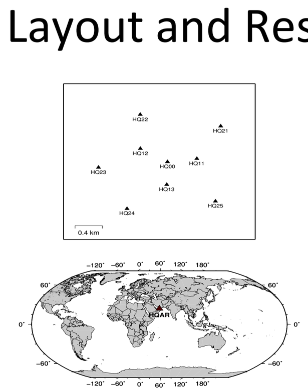
Layout and Response at QWAR

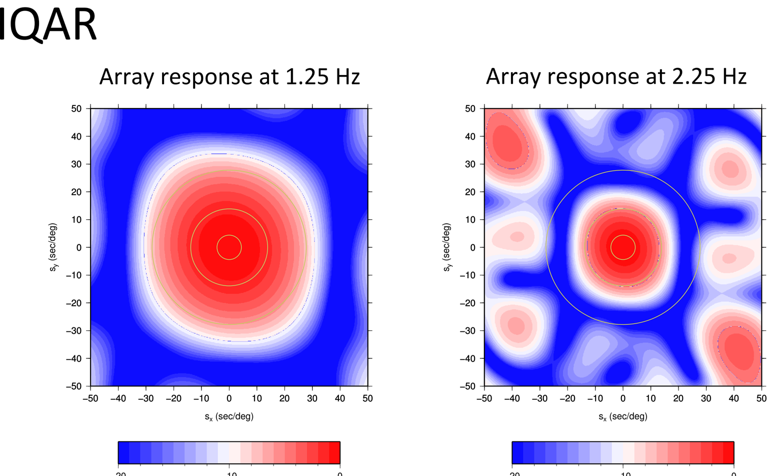




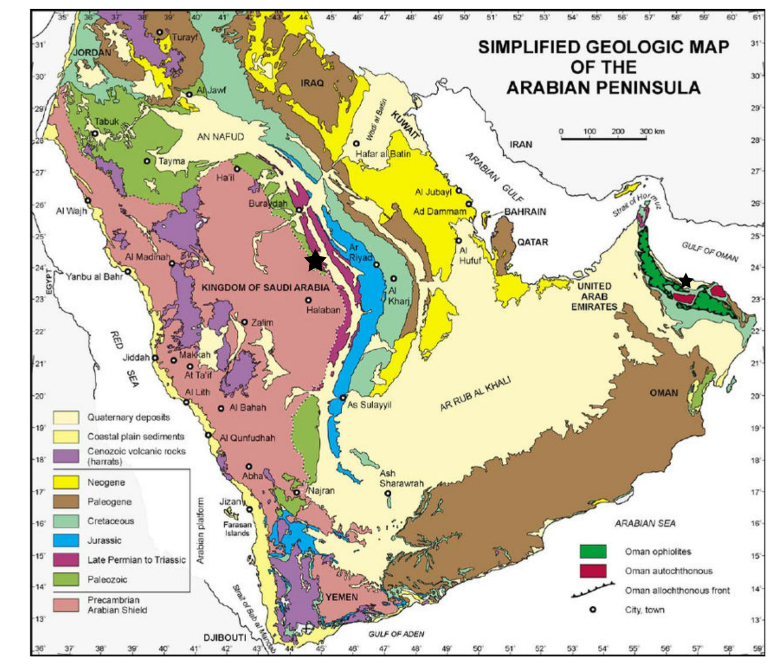
- An important consideration in array analysis is the possibility of spatial aliasing due to the discrete sampling of the wavenumber of a signal. The response functions plotted here show the array response to a vertically incident wave at varying frequencies.
- At low frequencies, the main lobe is quite large, indicating poor resolution of apparent velocity or azimuth.
- As frequency increases, the main lobe becomes smaller and sharper indicating better slowness resolution, however the sidelobes, which indicate possible spatial aliasing, also become more closer and more prominent.
- In order to balance increasing slowness resolution and decreasing spatial aliasing, we select a frequency band from 1-4 Hz for analysis.

Layout and Response at HQAR





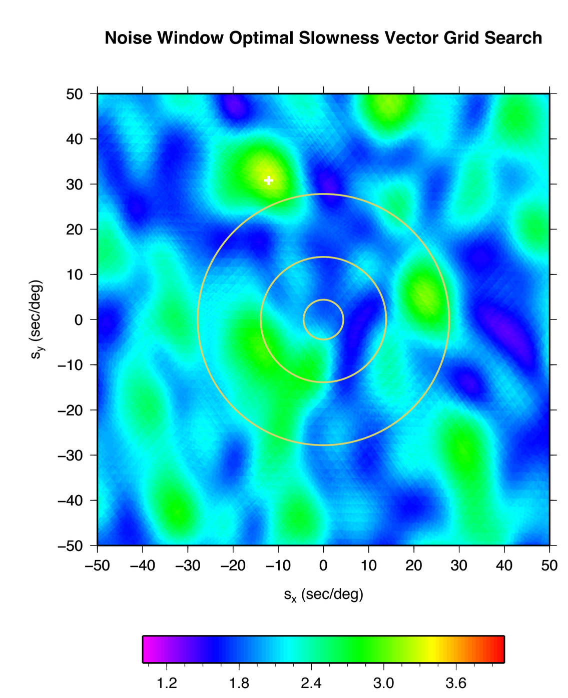
The main lobe at HQAR is slightly larger than that at QWAR at 1.25 and 2.25 Hz, due to the slightly smaller station spacing of the array. In general, the array responses are quite comparable.



Location map of the Arabian Plate and stations (left) and major geologic and tectonic elements of the Arabian Peninsula.

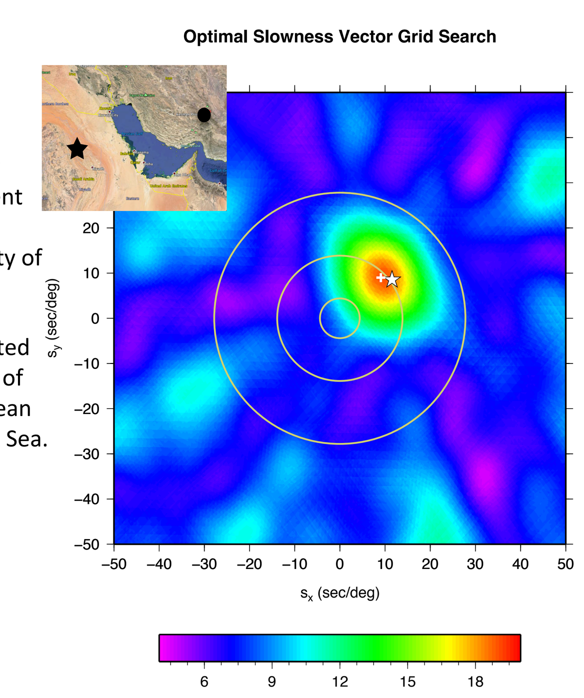
Beamforming Analysis at QWAR

Below are examples of our time-domain beampacking grid search for the optimal slowness vector. The expected P-wave arrival is determined using the ak135 model (Kennett *et al.*, 1995) and refined using a sliding window. The noise window is defined as a 10-second window that occurs 60 seconds before the expected P-wave arrival. In both cases the white cross shows the optimal slowness vector, for the event, the star shows the theoretical vector.



Optimal noise slowness vector suggests coherent noise with an apparent velocity of ~3.2 km/s.

Possibly generated along the shore of the Mediterranean Sea or the Black Sea.

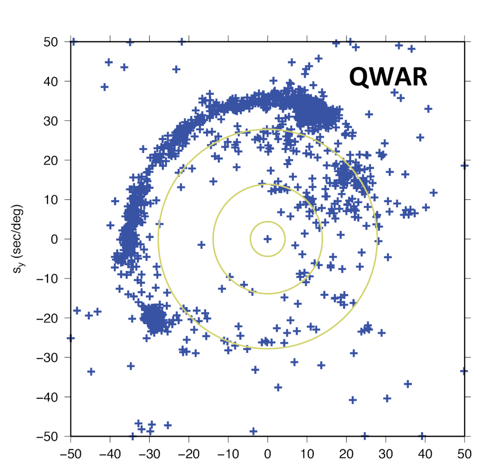


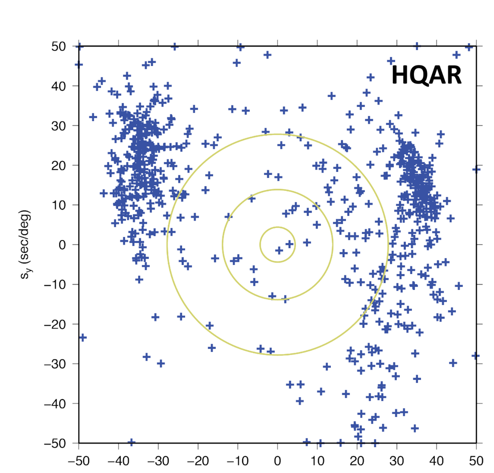
Optimal P-wave slowness vector is from a 3.5 Mb event in the Kerman Province, Iran.

Yellow circles show apparent velocities of 25 km/s (smallest circle), expected for core phases, 8 km/s (middle circle), expected for P-waves, and 4 km/s (largest circle), expected for S-waves.

Array-determined backazimuth is 45.3 degrees, close to the theoretical backazimuth of 53.6 degrees.

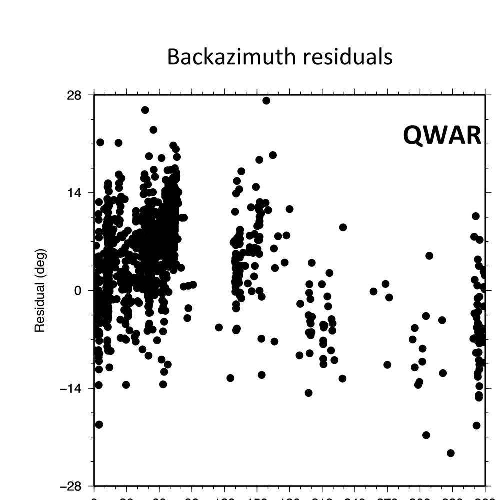
Coherent Noise at the Arrays

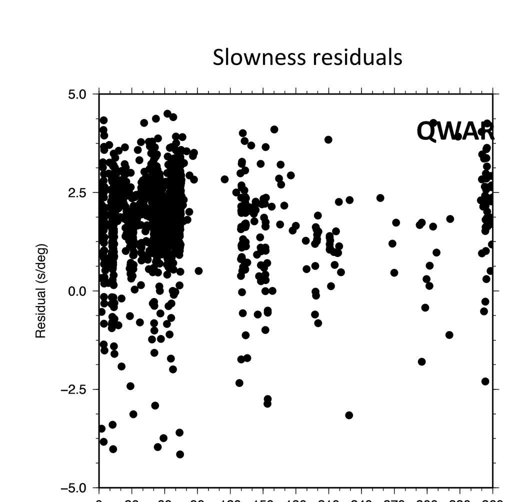




- Coherent noise may affect an array's detection capabilities, so it is useful to understand where noise is coming from and how powerful it is
- Most powerful noise at QWAR comes in with an apparent velocity of ~3.2 km/s and is strong in the directions of the Red Sea, Mediterranean Sea, Black Sea, Caspian Sea, and Persian Gulf
- Most powerful noise at HQAR has an apparent velocity of ~3.0 km/s and is strongest towards the coastlines of the Persian Gulf and the Gulf of Oman. Note that HQAR in this plot has limited analysis (6-element) due to data transfer issues.

Array Performance in Location and Apparent Velocity

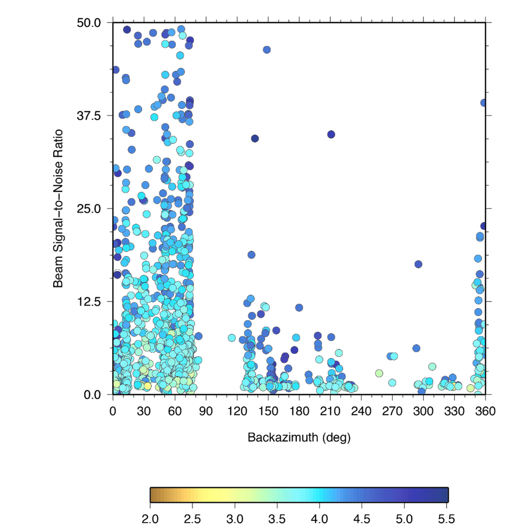




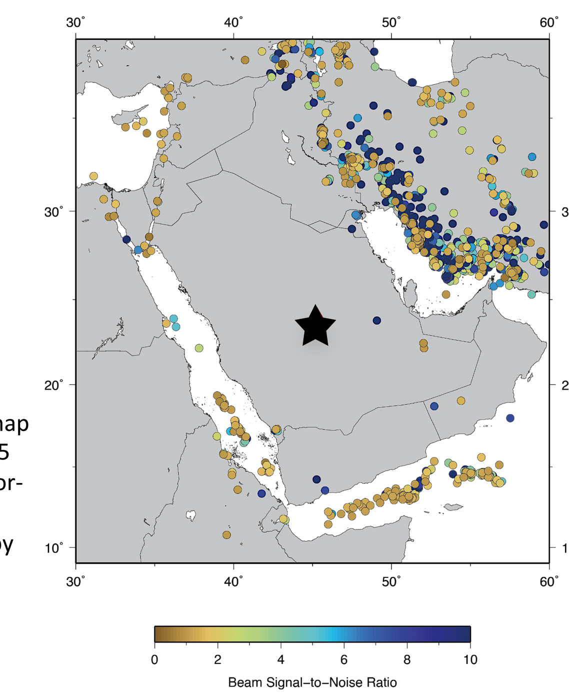
- Here we show the residual in backazimuth and slowness from the optimal array slowness vectors compared to the theoretical slowness vectors as a function of backazimuth Empirical corrections can be made to account for trends in the slowness/ azimuth discrepancies
- Variance of International Monitoring System (IMS) azimuth residuals without corrections generally between ~15-35 degrees while slowness variations between 1-2 s/deg [Bondar *et al.*, 1999]

Determining Array Detection Thresholds

- In order to understand the detection capabilities of the arrays, we examine beam signal-to-noise ratio (SNR) for events, and their relationship to event size, distance, and location. Here we show results at the QWAR array.
- Signal value is defined as the root mean square power of the optimal beam for the P-wave window.
- The noise value is defined as the power for the optimal beam formed using a 10 second noise window occurring 60 seconds before the expected P-wave arrival. Analysis is currently limited to catalog events, which are mostly Mb 3.0 and above.

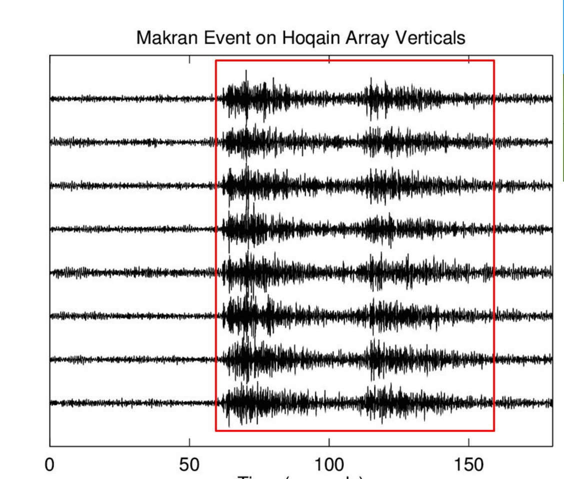


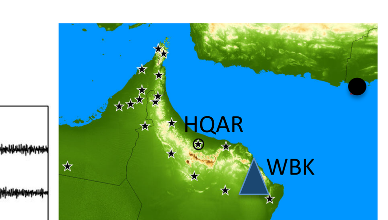
To the right we show a map of event locations with 15 degrees of the array, color-coded by the beam SNR. Array location is shown by the red triangle



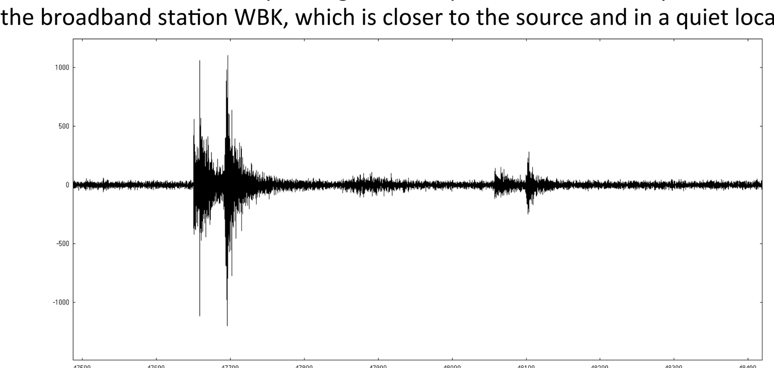
To the left we show the SNR as a function of backazimuth, and color-coded by event magnitude. Note that the lower SNRs observed to the south and southwest of the array are not due to smaller event magnitude.

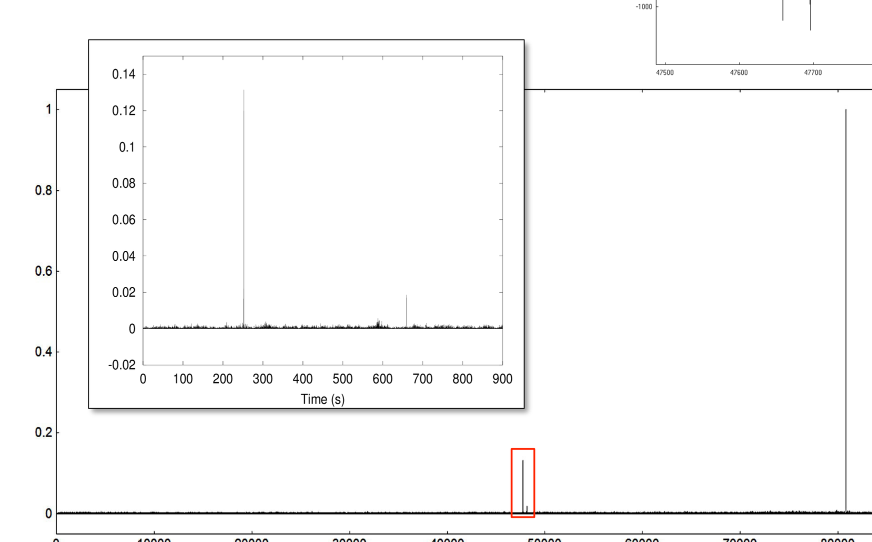
Correlation Detections





One hundred second template constructed from observations of the January 10, 2016 mb 3.5 event. Detection statistic for the array detector applied to the continuous stream from the HQAR array for January 10, 2016. The master event produced the peak (detecting itself) seen late in the record around 82,000 seconds. Two smaller peaks appear between 45,000 and 50,000 seconds. The existence of events corresponding to these peaks is confirmed by observations at the broadband station WBK, which is closer to the source and in a quiet location.





Observation of the two foreshocks of the magnitude 3.5 event on the vertical channel of WBK. The event inter-arrival time matches the delay between peaks in the correlation detection statistic, corroborating the identification of these events. The larger of the two foreshocks also shows a possible T phase.

CONCLUSIONS

- Both array responses are similar at 1-4 Hz.
- Azimuthal and slowness residuals of both arrays are similar to IMS arrays.
- Magnitude detection thresholds show azimuthal variation due to higher attenuation in lithosphere within Arabian Shield than Arabian Platform.
- HQAR correlation detections improved identifications of larger number of events of Makran event aftershocks.

REFERENCES

Bondar, I., North, R.G., Beall, G., 1999. Teleseismic slowness azimuth station corrections for the International Monitoring System seismic network. Bull. Seismol. Soc. Am. 89, 989–1003.

Kennett, B.L.N., E.R. Engdahl, and R. Buland (1995). Constraints on seismic velocities in the Earth from traveltimes. Geophys. J. Int., 122, 108-124

Sponsored by the U.S. Department of Energy, National Nuclear Security Administration, Office of Nuclear Verification. The views expressed here do not necessarily reflect the views of the United States Government, the United States Department of Energy, National Nuclear Security Administration, or the Lawrence Livermore National Laboratory.

Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-POST-731741