INL/CON-21-63952-Revision-0

Persistent Acoustic Sensing for Monitoring A Reactor Facility - Oral Presentation

August 2021

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Changing the World's Energy Future

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Persistent Acoustic Sensing for Monitoring a Reactor Facility

Work performed for the Multi-Informatics for Nuclear Operations Scenarios venture.

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August 24, 2021

Idaho National Laboratory

Multi-Informatics for Nuclear Operations Scenarios

Focus: Fuse data from multiple sensor types to characterize operations occurring at HFIR and REDC.

- Electromagnetic
- Thermal
- Radiation
- LiDAR
- Seismic
- Infrasound & Low-frequency

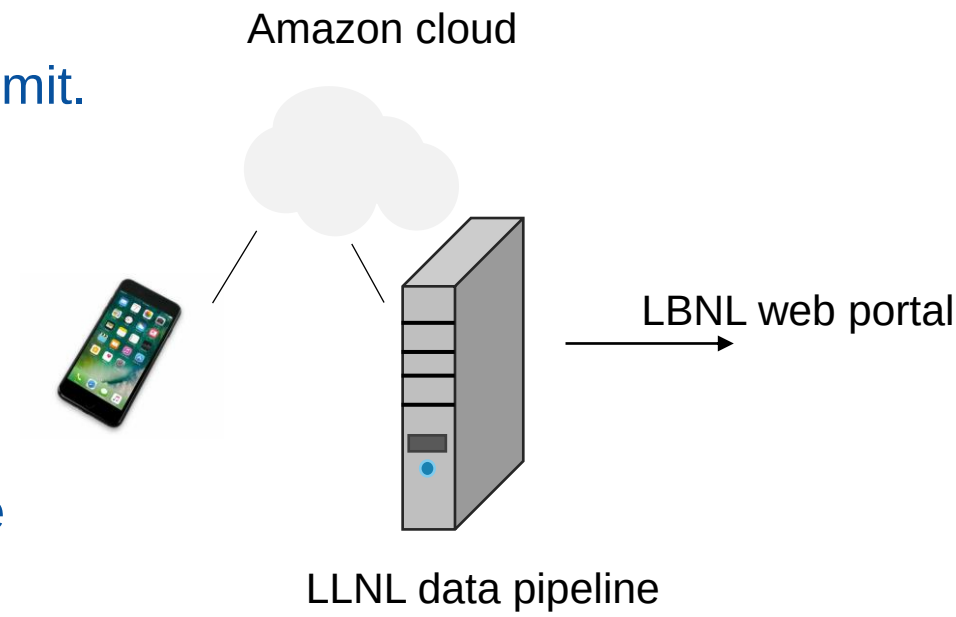
Google Earth Pro, (2020) *HFIR and REDC at ORNL* 35° 55’09.40” N, 84° 18’07.67” W, elevation 363 m. 3D building's layer.

Acoustic sensors use the built-in microphone on Samsung Galaxy S10 smartphones.

- 10 smartphones are installed
- Persistent monitoring

Acoustic Data Collection

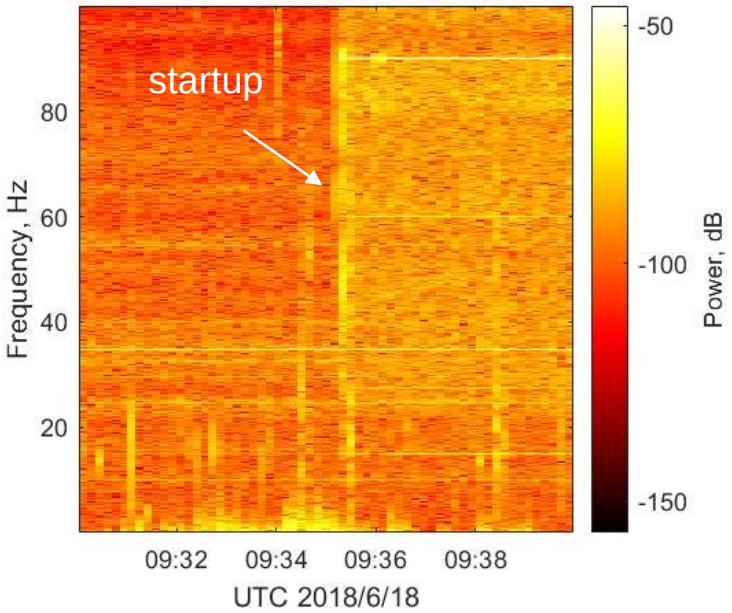
- Sensing smartphones use the RedVox Infrasound Recorder mobile application.
- Infrasound – 20 Hz frequency limit.
- We include & analyze up to approximately 380 Hz.
- Data streamed to the Amazon cloud.
- Data transferred daily to a data pipeline at Lawrence Livermore National Laboratory.
- Data sent to a web portal at Lawrence Berkeley National Laboratory.



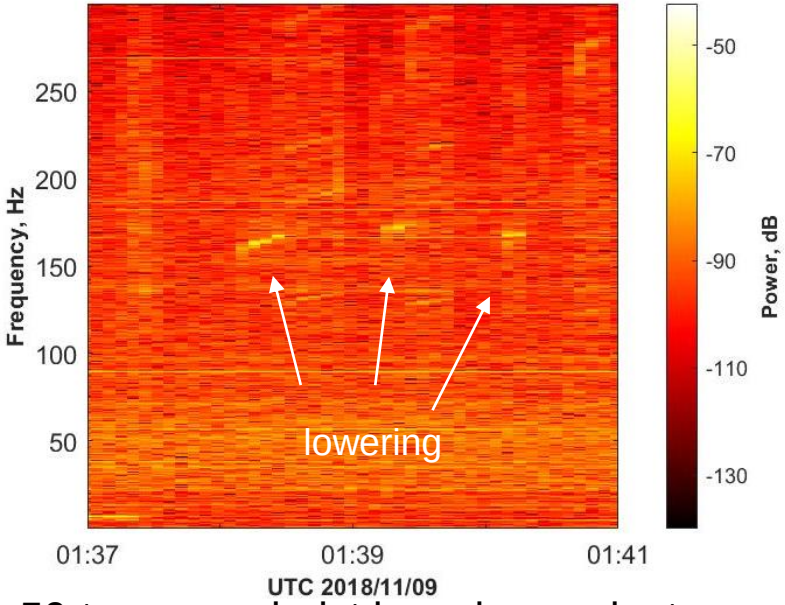
Signal Discovery

Observable operations:

- HFIR cooling tower fan
- HFIR crane
- REDC crane
- Diesel generator



Back diesel generator at REDC.



50-ton crane hoist lowering cask at HFIR.

Transfer Materials from HFIR and/or REDC

- Can we determine when radioactive material is transferred from HFIR and REDC?
- Typical transfer events include:
  - Air lock door operations
  - Heavy truck movements
  - Crane operations

- Acoustic sensors
- Seismic sensors
- Electromagnetic sensors
- Radiation sensors

HFIR exterior airlock truck door.

Programmed Notification Algorithm

- Inform of the occurrence of a transfer events at HFIR.
- Facilitate follow-up investigation;
  - Additional acoustic analysis.
  - Analysis from other sensors.
- Allow for a more focused effort during specific time frames.

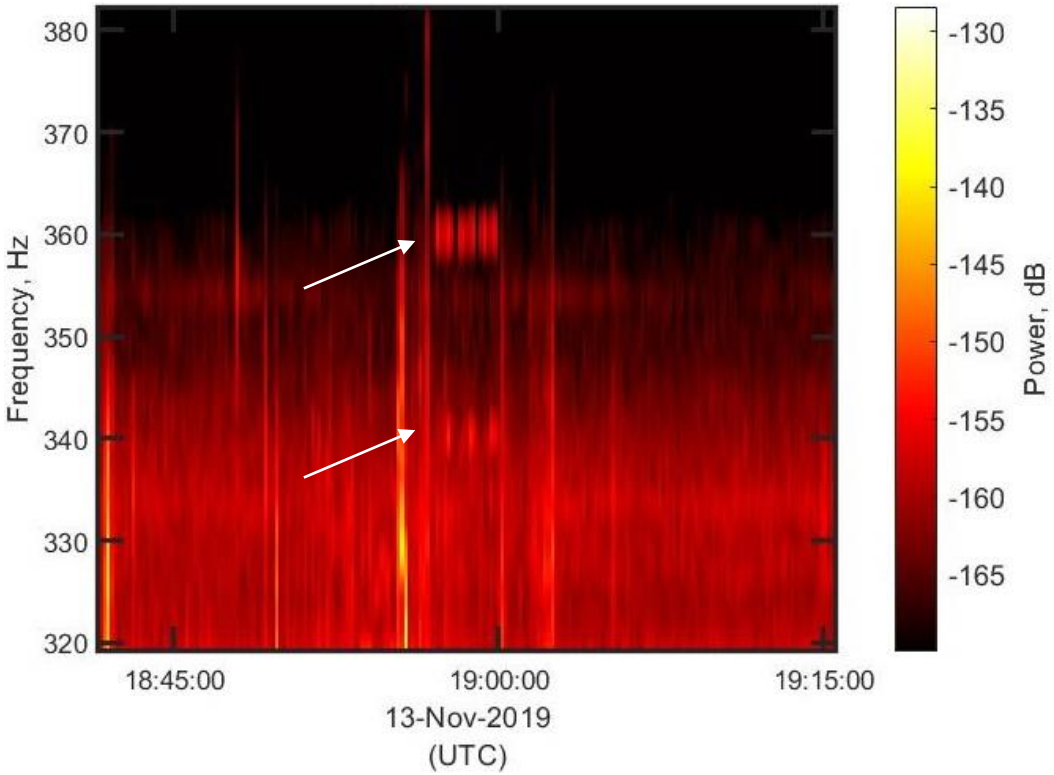
HFIR Airlock

- Start by using data collected from acoustic sensor around the corner from the HFIR airlock truck door.
  - Closest in proximity to transfer event.
- Data collected during the time of known airlock truck door operations.
  - November 11, 2019
  - Planned events

Acoustic sensor in weatherized enclosure.

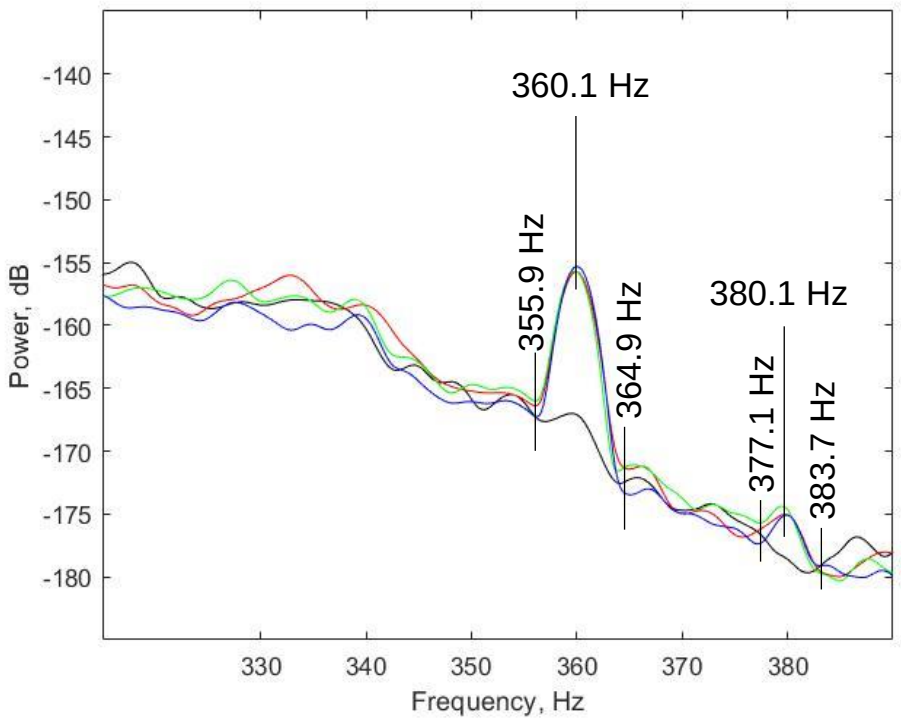
Airlock Truck Door Planned Operations

- ORNL staff was asked to open and close the exterior airlock door 3 times.



Airlock Truck Door Opened

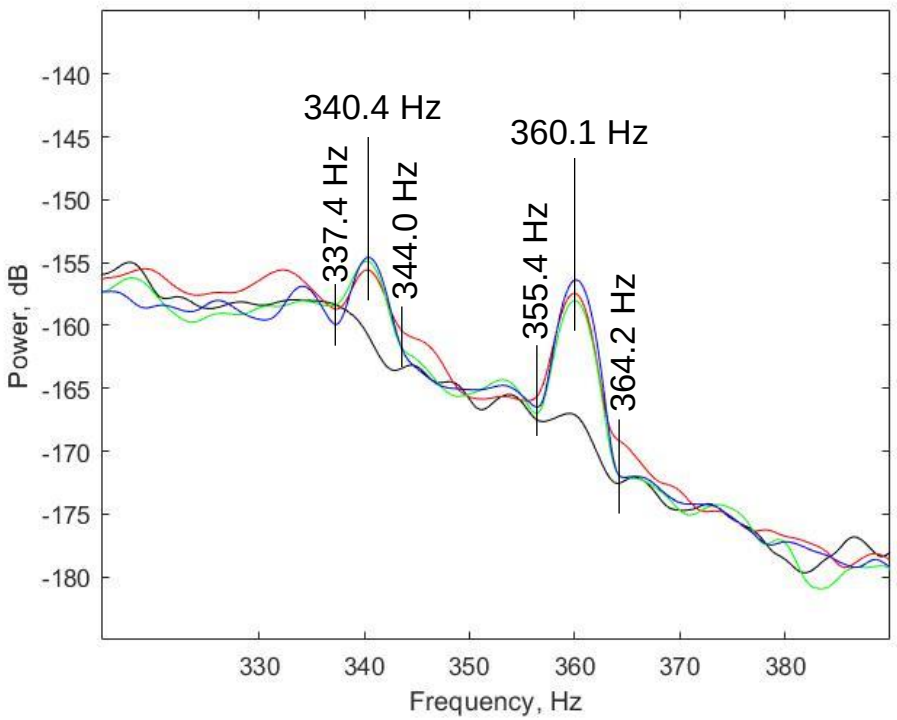
- Two peaks observed; at ~360 Hz and ~380 Hz.



Background (—), signals from known times when airlock door opened in (—), (—), and (—).

Airlock Truck Door Closed

- Two peaks observed; at ~360 Hz and ~340 Hz.



Background (—), signals from known times when airlock door opened in (—), (—), and (—).

Two-Sample T-test & Algorithm

Determines whether the signal and the background power samples come from distributions with unequal mean values.

- t, MATLAB®'s ttest2
- $\bar{x}$, signal mean
- $\bar{y}$, background mean
- s_x, signal standard deviation
- s_y, background standard deviation
- n, signal sample size
- m, background sample size

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{s_x^2}{n} + \frac{s_y^2}{m}}}$$

After input into the t-test the algorithm checks for unequal mean values between the samples for a duration of 24 seconds.

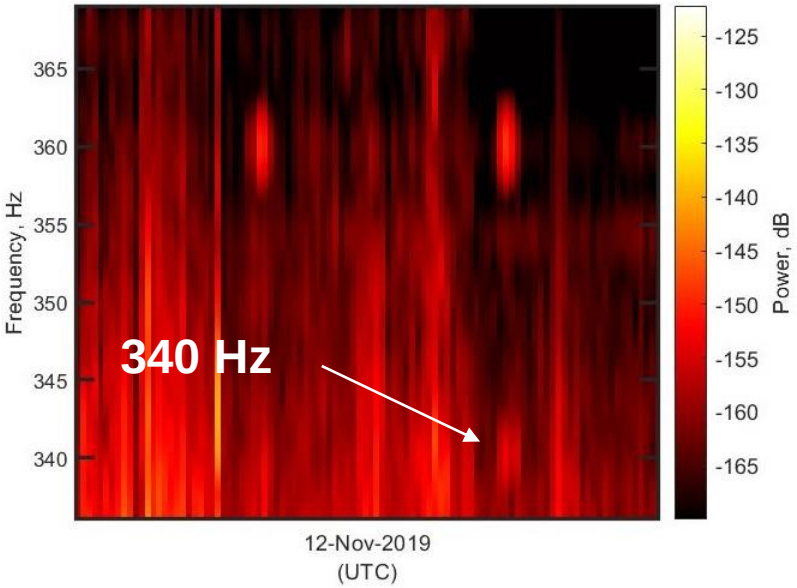
Results – Transfer Observed

- Algorithm successfully found instances of airlock door opening and closing on the directed operations.
- During week at ORNL the team recorded the transfer of spent fuel from HFIR.

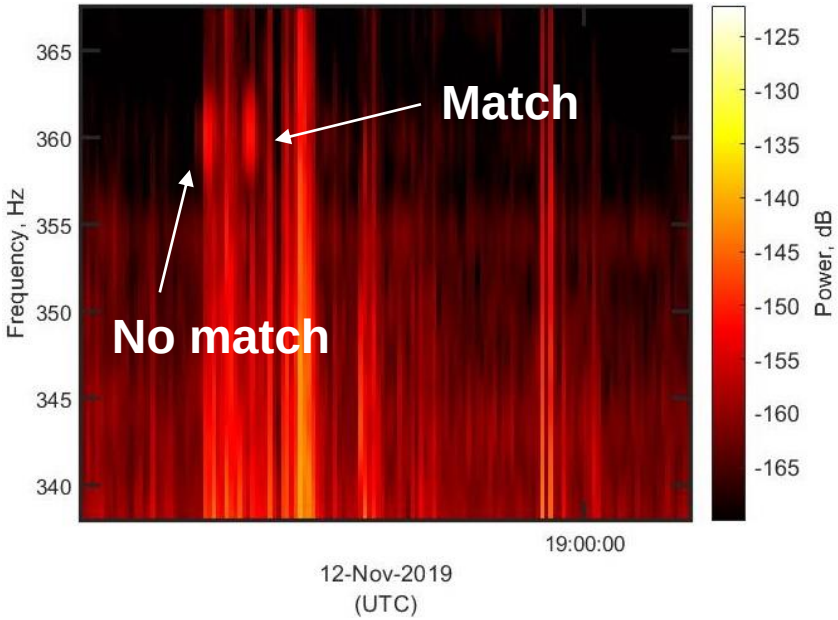
Airlock Operation	Recorded Start Time (UTC)	Recorded Finish Time (UTC)	Recorded Duration (s)	Notification Start Time (UTC)	Notification Finish Time (UTC)	Notification Duration (s)
Exterior door opens	18:52:34	18:53:00	26	No notification	No notification	
Exterior door closes	18:53:23	18:53:48	25	18:53:26	18:53:46	20
360-Hz peak found	Not observed	Not observed		17:42:33	17:42:54	20
360-Hz peak found	Not observed	Not observed		17:46:02	17:46:21	20

Results – Transfer Observed

- Three signals found at 360 Hz; one matching the time when the exterior airlock truck door was closed.
- Two signals found were prior to observations.



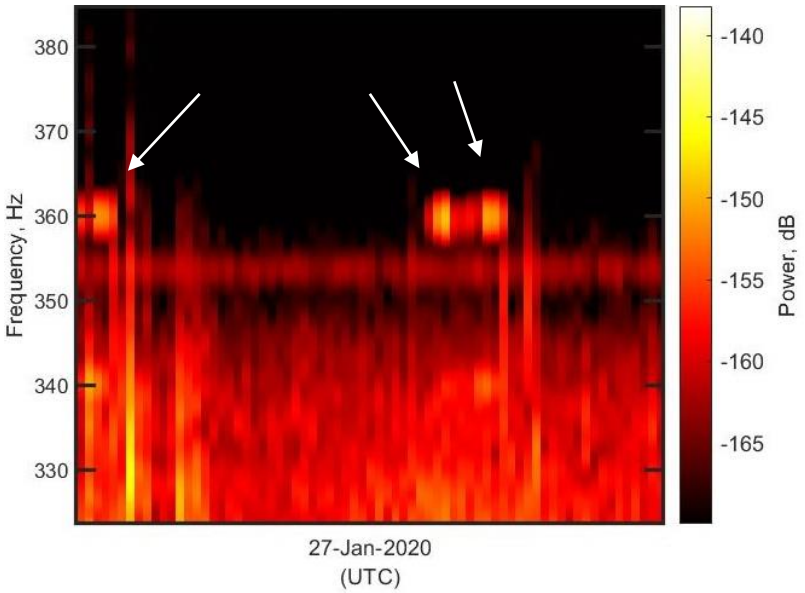
Signal not recorded by team from: 17:42:33 to 17:42:54 & 17:46:02 to 17:46:21.



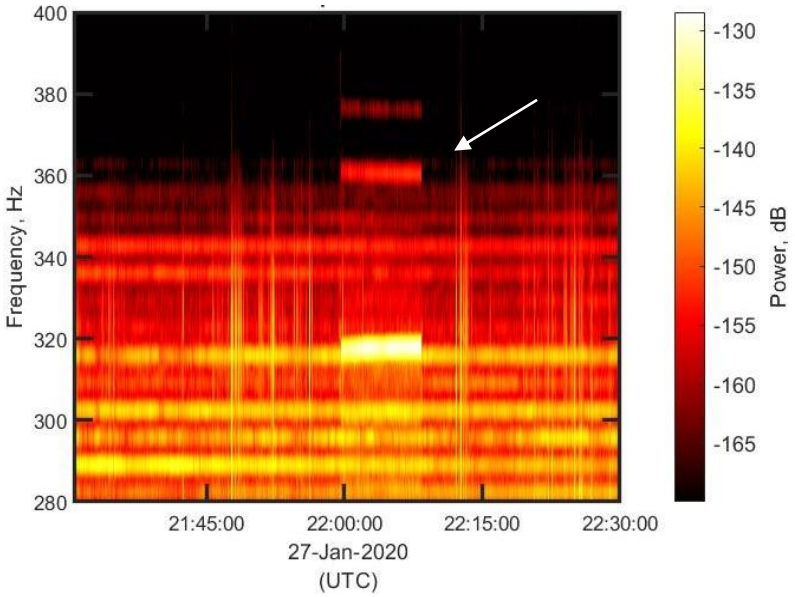
Signal matched recorded time by team from: 18:53:26 to 18:53:46.

Results – Spent Fuel Shipment

- Algorithm tested on known date when transfer occurred.



360 Hz peaks found beginning at 11:00:31, 11:04:00, and 11:04:20 UTC.



Twenty-six 360 Hz peaks found beginning at 21:30 UTC.

Conclusions – Notification Algorithm

- Using a two-sample t-test and timing analysis, the notification algorithm has discovered characteristic signals that occur in a pair and for a duration that is similar to the opening or closing of the exterior HFIR airlock truck door.
- The algorithm fails at discovering signals when there is noise in the frequencies at or near (within 10 Hz) the 360 Hz peak.
- The algorithm reports false positives when 360 Hz power increases occur in the next time bin from the previous one detected.
- These limitations can be overcome by analysis from other local sensors.
- The work was intended to facilitate further analysis from other local sensors allowing them to focus their efforts around discovered times.

Future Work

- Dates discovered need verification by other local sensors.
- Analysis on smartphones at other locations at ORNL.
- Additional analysis on dates where there was potential airlock door operation is necessary to test reliability.
- Improvements to the notification algorithm:
  - Automate detection of signal pairs.
  - Automate detection of 340 Hz peak.
- Implement in near-real-time.

Thank you.