

## Acoustic Emission Linear Location Cluster Analysis on Seam Welded Hot Reheat Piping

The EPRI Guidelines for acoustic emission (AE) inspection of seamed hot reheat piping were published in November 1995. The recommended data analysis procedures for both online and cooldown testing involve the evaluation of linear source location clusters. Acoustic Emission Consulting, Inc. (Fair Oaks, CA) has been integrally involved in EPRI R&D activities since 1988, and assisted in the development of data analysis strategies. AEC and Matrix Inspection & Engineering (Houston, TX) entered into a joint agreement in 1993 to develop instrumentation and analysis software to help standardize the application of AE to steam line testing. Since different instrumentation may be used in online (AET 5500) and cooldown (PAC SPARTAN) testing, there was a need to reduce the data to a common format for analysis and reporting.

The primary analysis procedures consist of identifying significant AE source location clusters through selective feature filtering and graphical analysis, selecting the cluster location limits, and compiling cluster statistics for ranking purposes. Data acquisition filtering consists of recording only those AE events that can be located within the source location array. This ensures that much of the typical noise encountered in steam line monitoring is ignored. Since standard AE data acquisition software is not well adapted for analysis of steam line AE, additional data conversion and analysis is performed. The flowchart shown in Figure 1 shows the data analysis steps. The data is converted from AET 5500 or SPARTAN binary format to ASCII database format through proprietary Windows-based programs. The ASCII data is then imported into the Excel spreadsheet program for statistical and graphical analysis.

Additional data filtering and graphical analysis in Excel is performed to validate the nature of the sources, and to establish correlation with plant operations. Significant clusters of located events are evaluated against selective criteria:

1. **Correlation with plant parameters.** Does the source activity correlate with line pressure and/or temperature excursions when higher stresses will be present. Figures 4 and 5 show plots of AE event locations and event rates plotted with plant parameters vs time. Some sources respond only to pressure conditions, others to a combination of temperature gradients and pressure, and some to thermal gradients alone. Understanding source behavior under online conditions is a key factor in interpretation. Sources that are responsive to high pressure, and show periodic activity peaks under steady-state conditions, are more typical of creep-related phenomena. Sources that are responsive only to thermal gradients may be responding to axial or bending loads, and are growing primarily by thermal fatigue.

2. **Correlation with AE features.** Do the average cluster features and patterns fall within the characteristic range typical of emissions from defect sources (Figure 2,3).

- The **Event Duration to Counts Ratio (ED/RDC)** is a measure of the compactness of the signal waveform. Typical values of this ratio are 4 to 20 for flaw-like AE signals. The inverse of this ratio is known as the pseudo-frequency, which is not the true frequency of the signal as determined by FFT methods. Typical pseudo-frequencies for flaw-like signals are in the range of 50-250 KHz for the KRNi400 sensor. The variation is due to differences in signal amplitude and signal morphology. Flow turbulence and other potential mechanical noise sources typically have pseudo-frequencies < 50 KHz (>20 ED/RDC ratio).
- The **Risetime** in microsecs of the signal envelope is also an indication of flaw-like sources. Risetimes for flaw signals are typically in the range of 25-500 microsecs. The further the source from the 1<sup>st</sup>-hit sensor, the slower the risetime value is likely to be because of waveform spreading and dispersion with distance. Flow turbulence and other mechanical noises sources tend to have very inconsistent risetimes, and typically show a great deal of scatter between values of 0-1000 microsecs.

- The **Peak Amplitude** in dB of AE signals is used to evaluate the intensity of the emitting source. Amplitude is affected by distance from the source to the 1<sup>st</sup>-hit sensor, and far field losses (beyond 2 ft from the source) are typically 0.5-1.0 dB/ft. Average cluster amplitudes are typically lower at the center position between two sensors because of attenuation losses. A range of signal amplitudes between 60-75 dB is typical of flaw-like sources.

3. **Structural location.** The physical significance of the a source location cluster is dependent on the likely source of emission: hanger, elbow, circumferential weld, long seam weld, etc. Sources may be invalidated if they occur at the center position between two sensors, have little location spread, and have inconsistent signal feature values. These peaks can be produced by sudden high noise or emission rates than cannot be accommodated by the floating threshold.

4. **Average activity per unit time, or energy release rate.** How does the activity rate compare among different clusters for a given period of equivalent stimulation.

The first three criteria are used to qualitatively evaluate the source location cluster for relationship to flaw-like sources. The fourth is used for quantitative ranking. Quantitative ranking is not absolute for sources on the same structure, or in comparing sources from different structures. Factors such as sensor spacing, source distance from the 1<sup>st</sup>-hit sensor, local noise levels, threshold and gain settings, pipe diameter and wall thickness---all can affect the perceived emission from an active AE source. AEC has developed normalization routines to mitigate some of these factors, but with the caveat that engineering judgment and experience are strong factors in the interpretation of quantitative characterization. The two primary techniques used in ranking sources in this test program were **Normalized Amplitude Ranking (NAR)**, and **Normalized Event Density Ranking (NEDR)**.

**Normalized Amplitude Ranking** (Figure 7) compares different clusters based on the ratio of cluster events with peak amplitude greater than a selected value (usually between 60-70 dB) compared to the total events in the cluster. It is very straightforward to apply as a spreadsheet method, and quickly yields a numerically comparative ranking between sources. The normalization is performed against both the peak and average activities per unit length of piping (usually 6-inch intervals). This method is typically applied when comparing sources that have seen the same stimulation or load exposure, such as a cooldown or online monitoring where stimulation is equivalent for a substantial span of structure. The **NAR** value is a logarithmic number, similar in concept to the Richter Scale for earthquake intensity measurement. However it lacks an absolute reference point due to the factors previously identified, and it does not imply the size or nature of the emitting source. A number of smaller sources in a limited distance span could contribute the same or more emission activity as a single, coherent defect, e.g. But the interpretation of defect severity would be strongly impacted by location, nature of the defect(s), and fracture mechanics considerations. The value of a numerical ranking, though not absolute, is nonetheless valuable in prioritizing follow-up inspections, and in trending analysis for comparison with future AE test results.

The **Normalized Event Density Ranking** was developed to deal with cluster analysis in the online testing mode specifically, since with current technology it is not likely that the entire HRH structure would be monitored at the same time and under exactly the same load conditions (% peak load operating time). The **NEDR** calculation attempts to normalize location clusters based on event density (source location scatter) and the operational profile. The calculation has units of events/inch-hr, and is determined for each cluster according to the following equation:

$$\frac{\text{TAE}}{\text{STD x HRS x PCT}}$$

TAE = Total Cluster AE Events (passing filter criteria of ED/RDC<=20).  
 STD = Cluster Location Std. Deviation (inches).  
 HRS = Operating Hours Monitored.  
 PCT = Percentage of time at >90% peak load.

Another graphical analysis methodology, **feature density plotting**, (Figure 9) provides a 3-dimensional view of source location data by allowing the density of a particular AE event feature value (e.g. amplitude, risetime, ED/RDC ratio) to be plotted against a location range. The density is depicted in topographic form as color or grayscale variations. With this graphical technique, discreet sites of emission in close proximity can be resolved more clearly than with a two-dimensional linear location histogram. It also assists in the selection of cluster location limits for analysis. The knowledge that a series of discreet sites in close proximity contributed to the emission cluster in a given area is very germane to the interpretation process. Even a series of low ranking (quantitative) clusters spread over an area of several feet on a seam weld could presage the development of a major flaw if these defect structures coalesce. The Amplitude vs. Location feature density plot was found to be the most valuable in resolving discreet emission sites.

# AE DATA ANALYSIS

Each line in database format is a source location event

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V		
1	TIME	TEST#	S1	S2	S3	S4	DT1	DT2	DT3	FDC	ED	PA	ENG	RT	SLOPE	PAR1	PAR2	PAR3	FMS	RG	LOC	ED/RDC	
2	42.36	1	2	3	0	0	1081	9999	9999	12	196	63	74	2	32	3770	6240	7870	80	1	225	8.33	
3	42.45	1	3	4	0	0	1702	9999	9999	320	1204	71	102	35	4	3760	8220	7690	140	1	370	3.76	
4	42.45	1	3	2	4	0	947	1784	9999	232	1262	64	95	262	1	3760	5220	7690	140	1	231	6.00	
5	51.41	1	4	3	0	0	1162	9999	9999	248	1200	63	94	269	0	3850	5200	7890	80	1	525	5.96	
6	91.17	1	2	3	1	0	1175	2011	9999	233	1288	65	96	160	1	4530	6390	7760	80	1	225	5.53	
7	102.7	1	3	4	0	0	763	9999	9999	279	1080	67	97	605	0	4440	6560	7900	80	1	417	3.97	
8	102.7	1	3	2	4	1	463	1795	2343	245	1040	68	98	231	1	4640	6560	7900	80	1	307	3.01	
9	104.21	1	4	3	0	0	1847	9999	9999	184	1212	62	92	202	1	4630	6600	7840	80	1	539	6.93	
10	104.22	1	4	3	0	0	1175	9999	9999	57	864	56	87	136	1	4630	6600	7840	80	1	594	16.86	
11	104.22	1	4	3	0	0	857	9999	9999	37	908	56	86	86	545	0	4630	6600	7840	80	1	488	24.54
12	104.24	1	3	4	0	0	397	9999	9999	123	644	59	96	227	0	4630	6600	7840	170	1	426	5.24	
13	106.38	1	4	3	0	0	275	9999	9999	40	1176	68	89	204	0	4590	6570	7810	80	1	463	29.40	
14	116.86	1	2	3	0	0	1174	9999	9999	13	308	54	79	49	1	4650	6640	7810	80	1	225	23.69	
15	117.2	1	3	4	0	0	424	9999	9999	29	528	56	83	181	0	4660	6610	7810	180	1	434	18.21	
16	117.96	1	3	4	0	0	414	9999	9999	296	1100	74	104	719	1	4650	6650	7800	170	1	435	2.76	
17	118.86	1	4	3	0	0	428	9999	9999	122	1452	59	90	280	0	4650	6590	7800	80	1	477	11.90	
18	118.91	1	4	3	0	0	1711	9999	9999	85	1640	63	95	415	0	4650	6610	7810	80	1	541	9.94	
19	118.91	1	1	2	0	0	1327	9999	9999	220	740	67	96	97	2	4650	6610	7810	270	1	47	3.36	

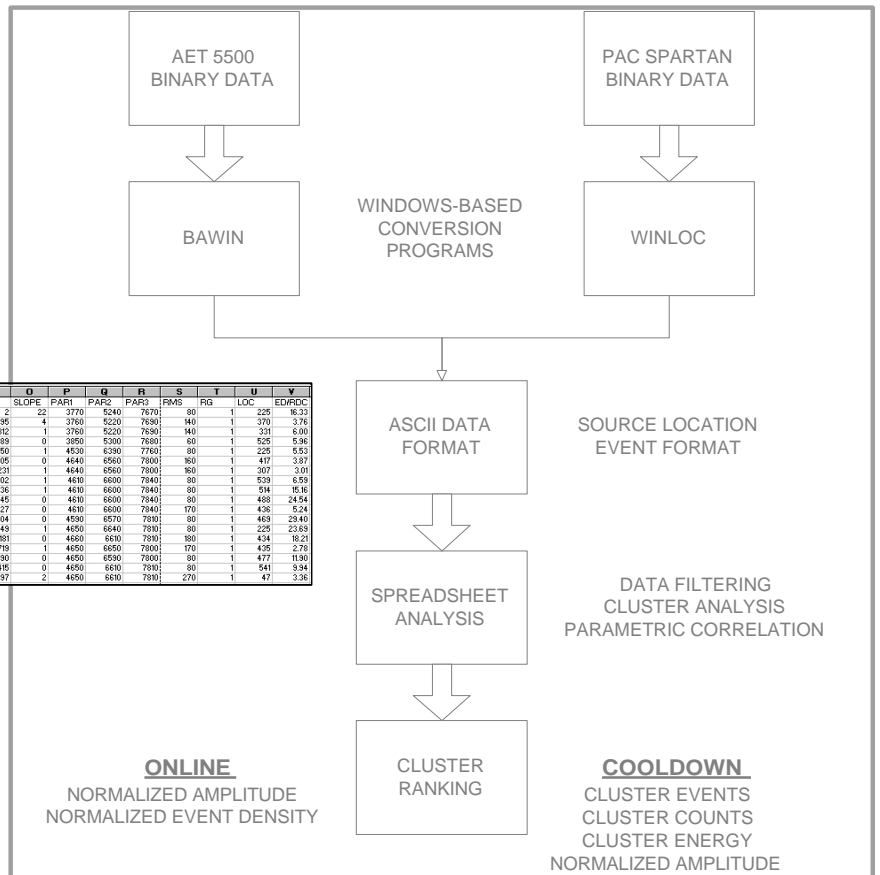


Figure 1. Data analysis methodology of AE linear source location data from HRH line testing, as practiced by AEC and Matrix.

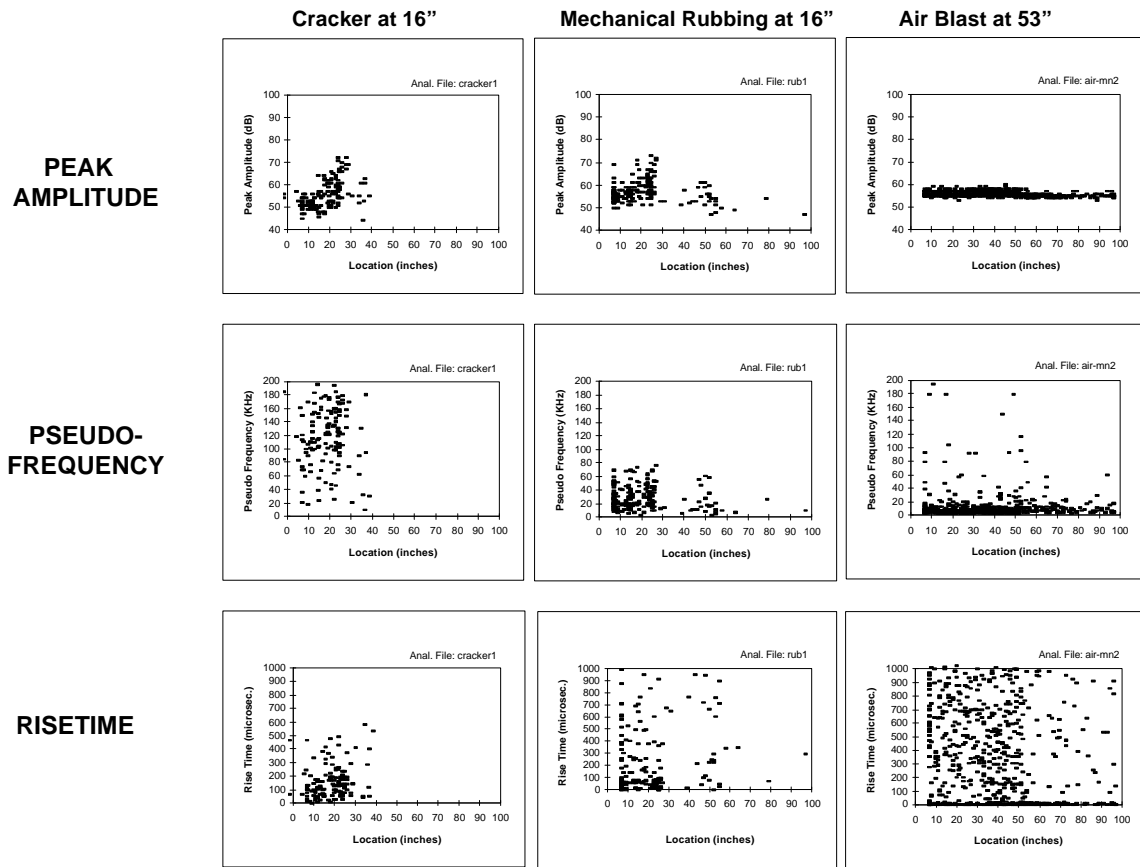


Figure 2. Examples of standard AE features which proved particularly powerful in separating mechanical and flow noise from crack-like emissions. Pseudo-frequency is a powerful indicator of the compactness of the emission source. Crack-like signals from 300-400 KHz sensors tend to have pseudo-frequencies in the range of 60-200 KHz (threshold and signal amplitude factors account for the scatter). Mechanical rubbing and flow noise have less waveform definition, and generally have pseudo-frequencies of <50 KHz. Signal risetimes for crack-like sources are faster and more consistent, in the range of 50-400 microseconds. Risetimes for mechanical sources are very inconsistent and show scatter between 0-1000 microseconds.

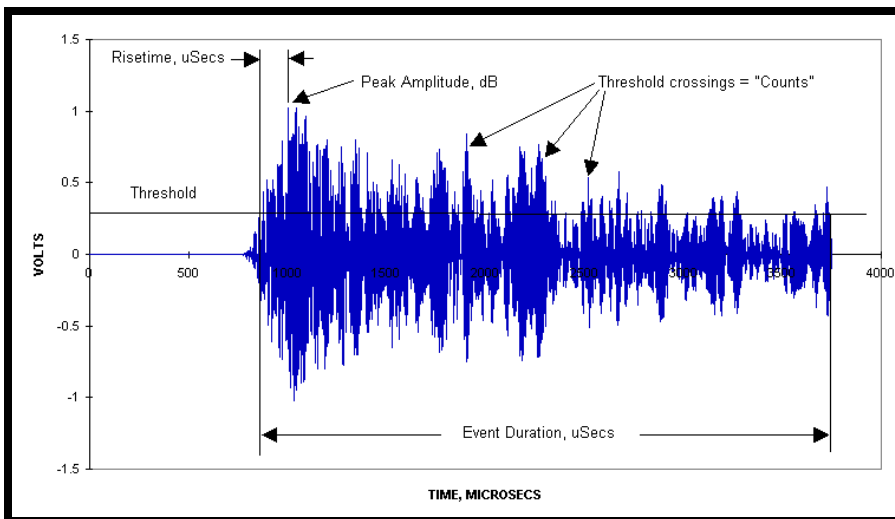


Figure 3. Standard definitions of AE signal waveform features. Not shown is pseudo-frequency, which is *counts* divided by *event duration*. Pseudo-frequency is not the actual frequency response of the sensor, but is an indicator of the compactness of the signal waveform.

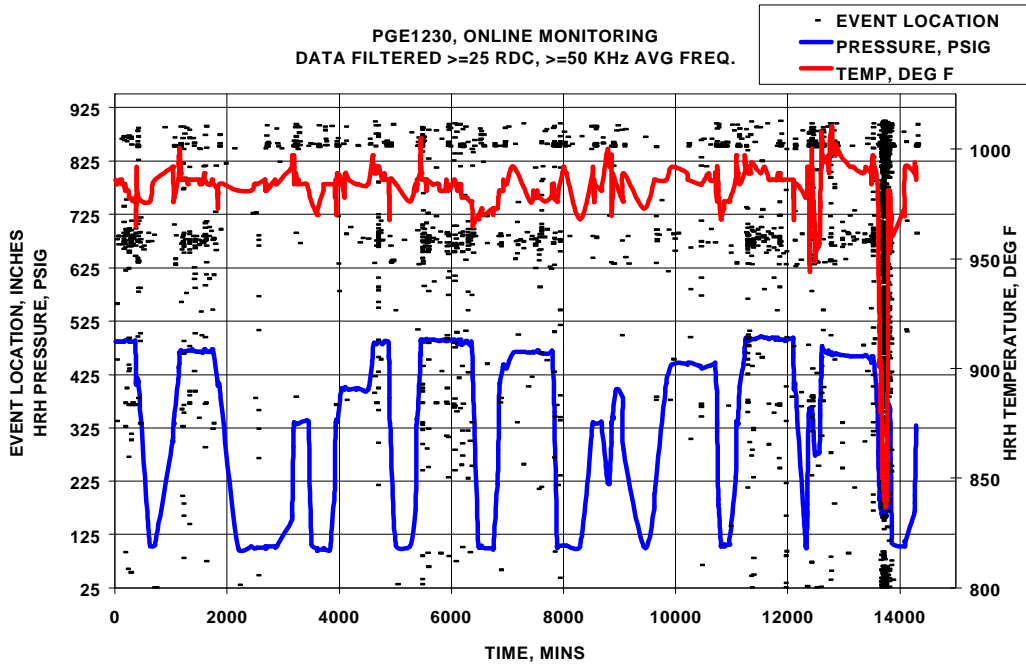


Figure 4. Example of online AE source location data and plant parameters vs time. The cluster at location 690 inches is a series of defects (cracks, shrinkage porosity) in a cast elbow. It is primarily responsive to high pressure conditions. The cluster at 860 inches is a cracked hanger saddle weld. It is primarily responsive to thermal transients associated with load changes. At about 13700 mins, the loss of primary turbine pressure results in a steep decline in temperature, from 980 to 830 deg F.

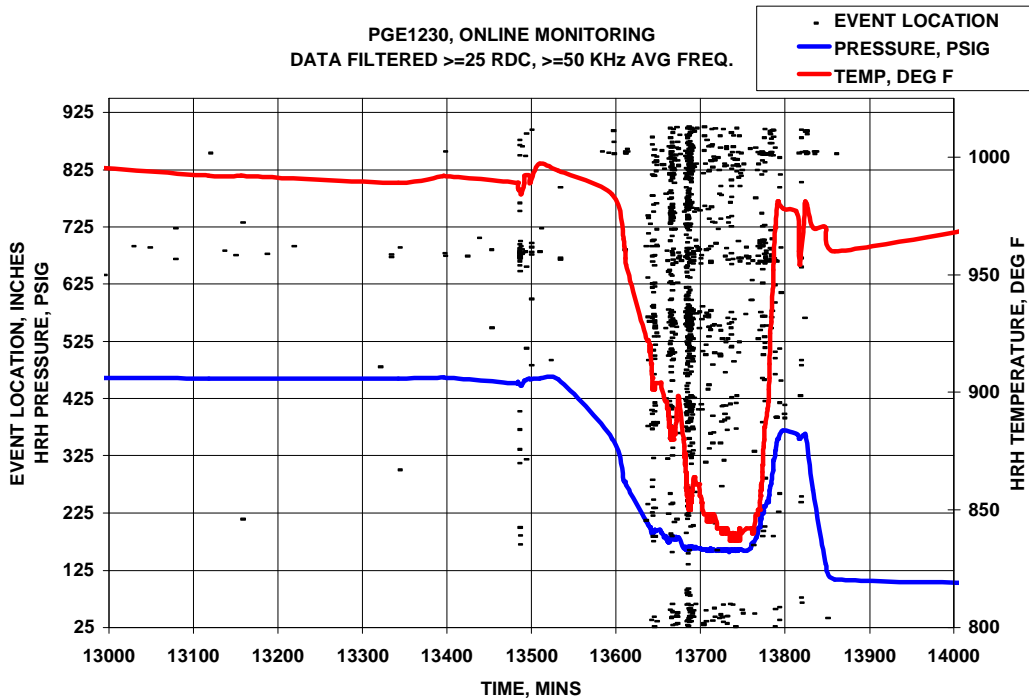


Figure 5. Expanded time scale of the deep thermal transient from Figure 3. Note that many more sources along the line are excited by the rapid cooldown, which reached peak rates of 300 F/Hr.

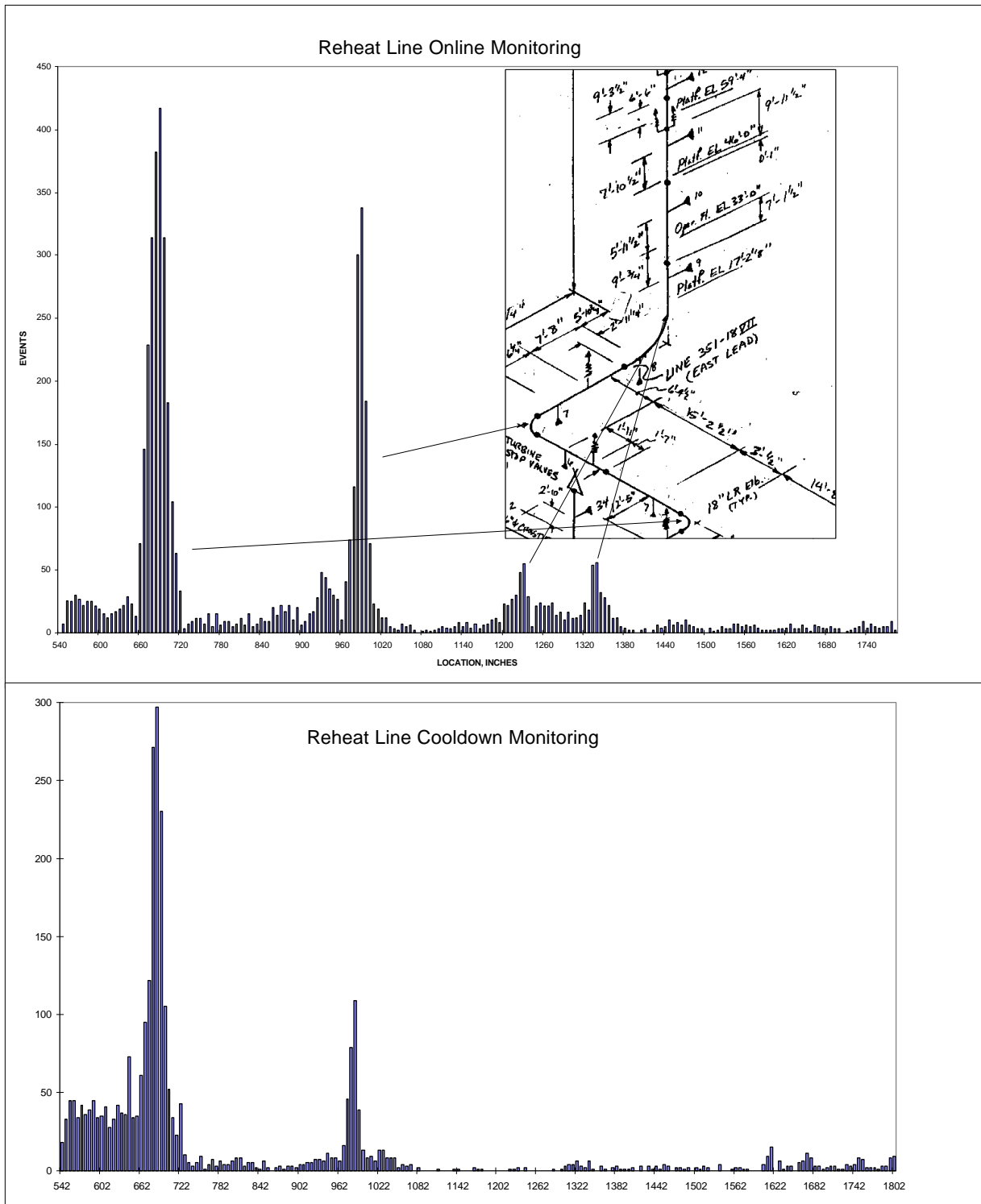


Figure 6. Comparison of linear source location results from online (top) vs cooldown (bottom) for a segment of 18" OD HRH line. The elbow between location 600-700 is the same as referenced in Figure 3. Note that the upstream elbow at location 1000 is a much stronger emitter in the online vs cooldown mode. There are also some smaller clusters developing in the vertical bend upstream of the elbows, but they are seen only in the online mode. The hanger saddle weld referenced in Figure 3 had been repaired before this testing, and is observed in neither testing mode.

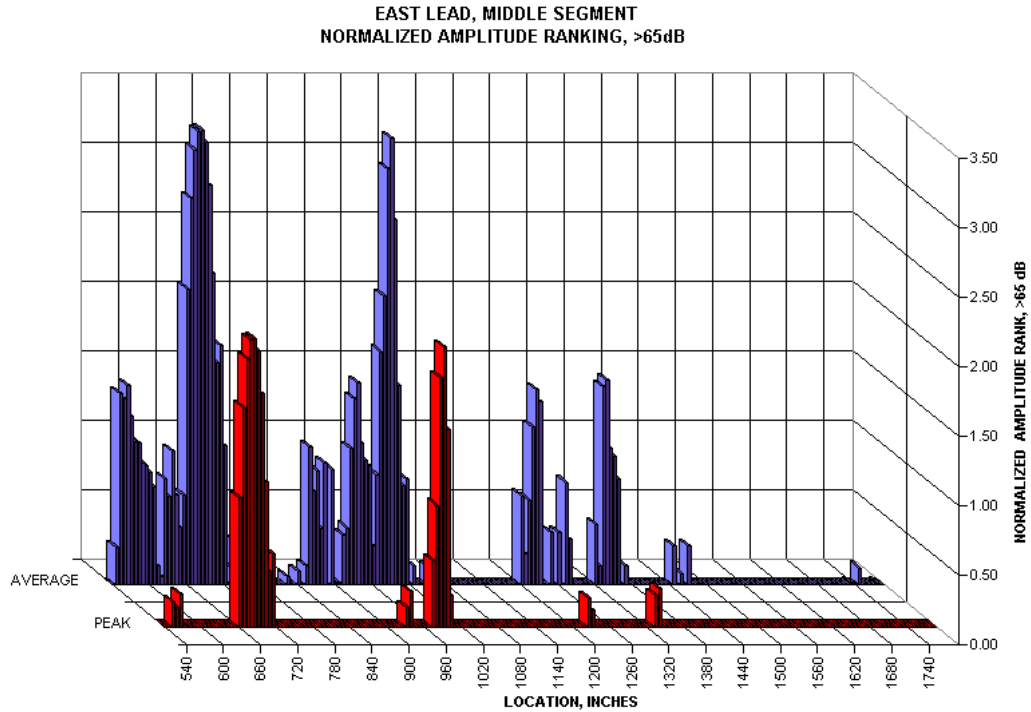


Figure 7. Normalized amplitude ranking from the online data depicted in Figure 5. The NAR is a logarithmic value similar in concept to the Richter Scale for earthquake intensity measurement.

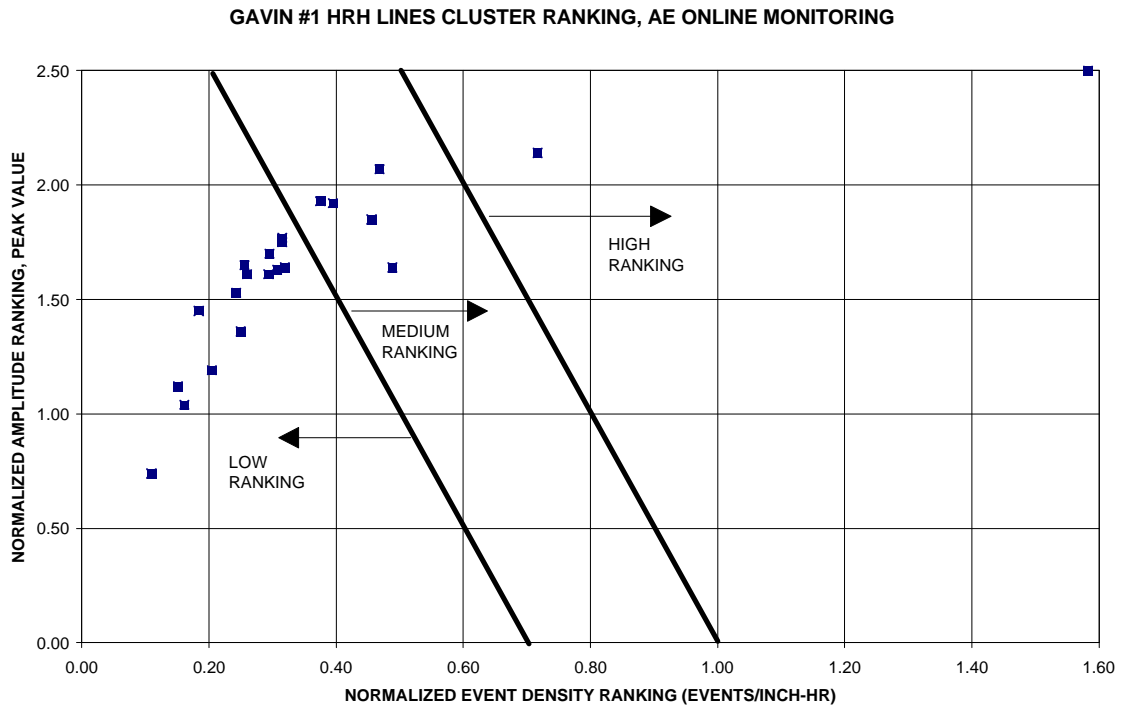


Figure 8. Example of overall AE source location cluster ranking based on a combination of Normalized Amplitude Ranking and Normalized Event Density Ranking from a 1996 online monitoring test program. High and medium ranking sources were recommended for inspection.

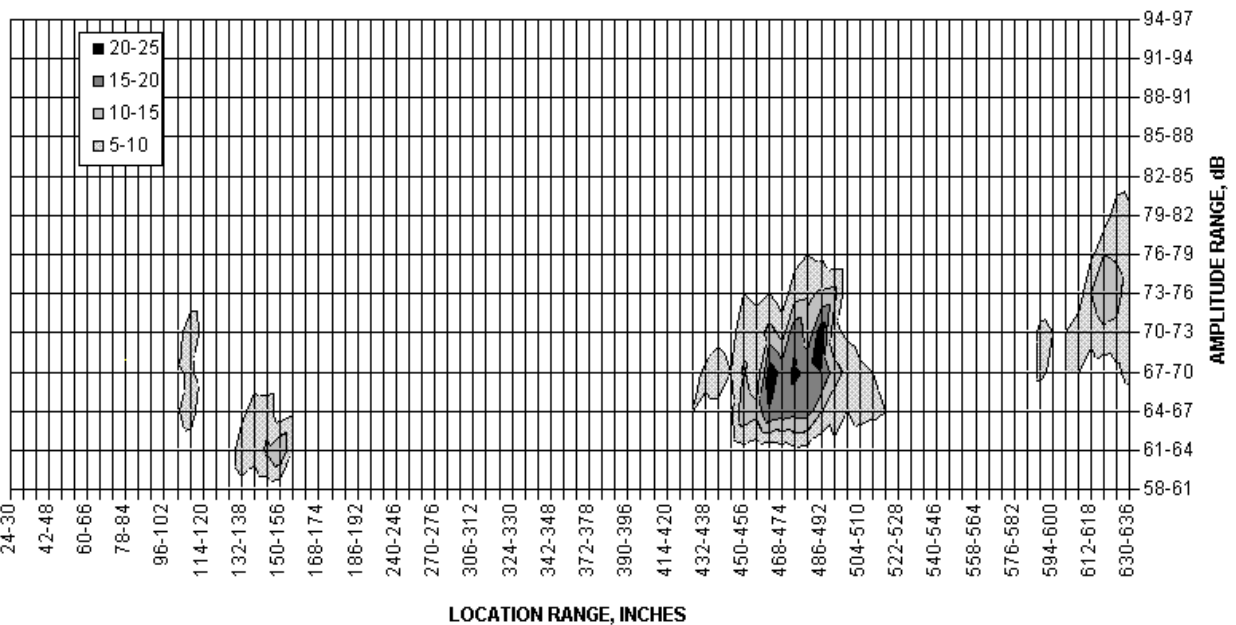
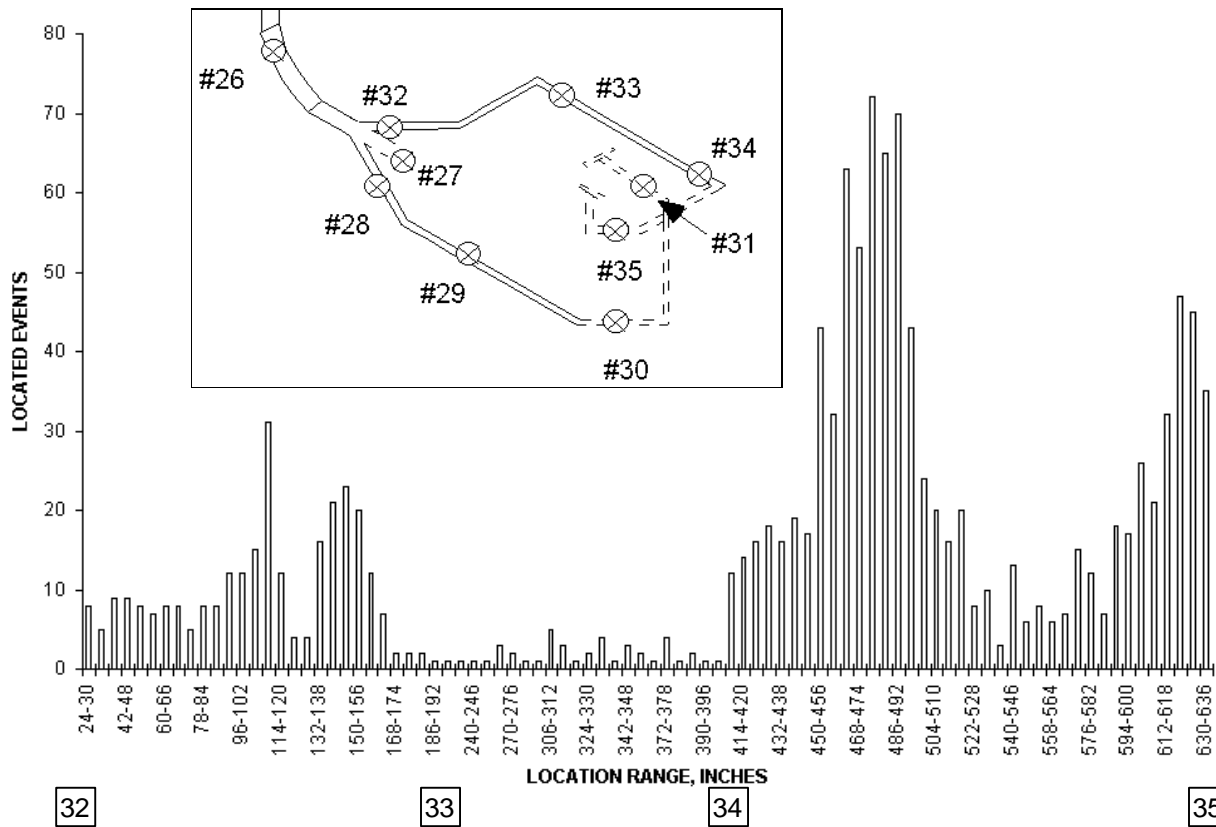


Figure 9. Example of advanced cluster analysis of field source location data from online monitoring. Inset above shows turbine lead covered by waveguide #'s 32-35. The linear source location plot above shows activity primarily at elbow positions. The extensive location cluster at positions 420-520 actually resolves into discrete sites of concentrated activity when viewed as a feature density plot of signal peak amplitude vs location (bottom).