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GT POWER GENERATION STATIONS IN NOISE SENSITIVE AREAS

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Abstract

Noise impact estimates based on a simplistic source model tend to over-predict the actual sound levels. More detailed emission models are needed during the initial planning phase to help assess the cost of any noise controls. The ubiquitous point sources are replaced with line and area sources. The result is a more precise distribution and description of the source region, and the ability to examine the relative contributions of the various components to the overall sound, as well as means of mitigating excessive noise.

1 Introduction

One of the considerations in selecting a suitable site for a power generation system is the potential impact on off-property receptors. Before an operating license is issued, a proponent must demonstrate that air and noise emissions comply with applicable standards for air quality and noise. These issues must be considered during the preliminary planning states, as they impact project cost and possibly project viability. During the initial planning phases many of the details of the power plant are not well define**d**. Nevertheless, it is essential that the noise impact be quantified, as it has an impact on system configuration, as well as potential land acquisitions. The methodology described herein has been developed to assist the developer during the planning phases.

2 Noise Impact Assessment

Noise impact is normally assessed in terms of an hourly equivalent sound pressure level (Leq). This single number metric, usually reported in terms of dBA, represents the steady sound pressure level that has the identical dose of acoustic energy as the actual, possibly fluctuating level at the point of reception. Allowable night-time levels are usually 5 dB lower than day-time levels and drive noise control considerations. It is obvious that significant noise intrusion for rural sound-scapes occurs at lower sound pressure levels than in urban surroundings.

3 Sound Propagation

Although the plant-listener separation is greater in most rural settings, this does not assure that noise impact is insignificant. The Ontario noise limits for a power generating plant located in a rural area are set by the night-time exclusionary limits of 40 dBA. Using the ubiquitous formula that relates sound pressure level (SPL) at a distance R to the sound power level (Lw):

$$\mathbf{SPL=Lw-20log_{10}R-8} \qquad (1)$$

One may estimate the maximum sound power level that can be emitted by the power generation station. Figure 1 is a graphic illustration for the case SPL=40 dBA. Typical sound power levels of simple cycle machines are of the order of 110 to 130 dBA. It is evident from Figure 1 that large set-back distances are required; if no noise controls are applied to such units.

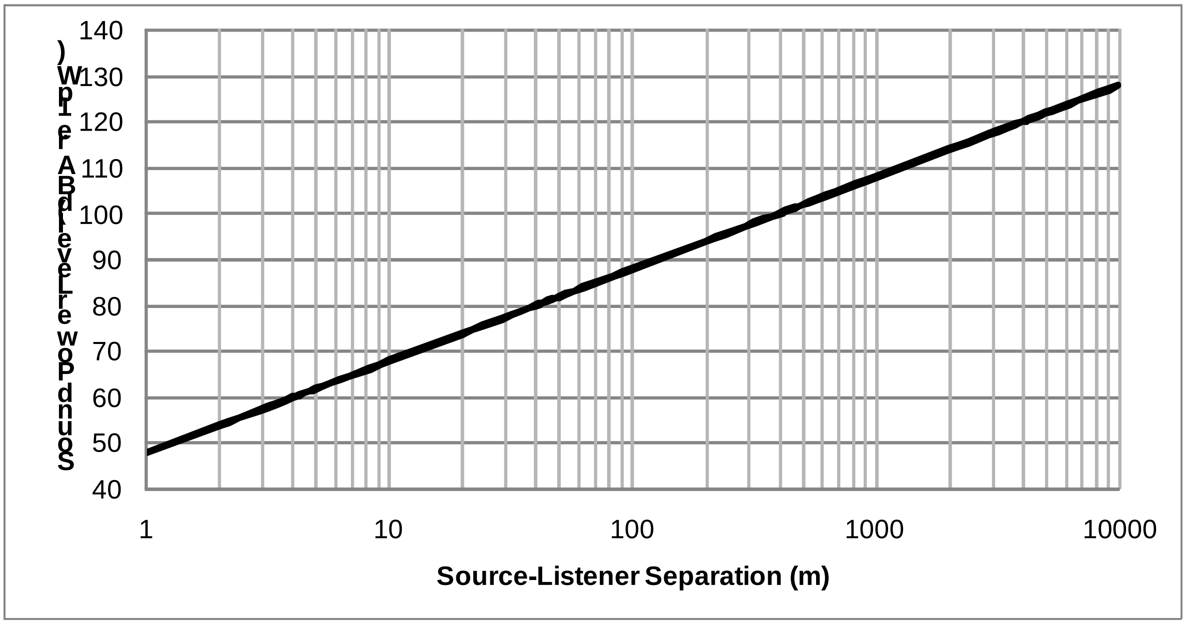

Figure 1: Maximum power level (L_w) as a function of source-listener distance (R).

The above equation is valid for 'hemi-spherical' spreading over a hard, perfectly reflecting ground. It is obvious that this is a poor approximation for sound propagation outdoors. Sound typically propagates through a real atmosphere, over non-flat ground. Air absorbs a certain percentage of the acoustic energy, thereby diminishing the overall sound pressure level. The effect of atmospheric absorption is frequency dependent, with the higher frequencies suffering more loss than lower frequencies. For source receiver separations greater than 250m, atmospheric absorption becomes a primary mechanism of sound attenuation.

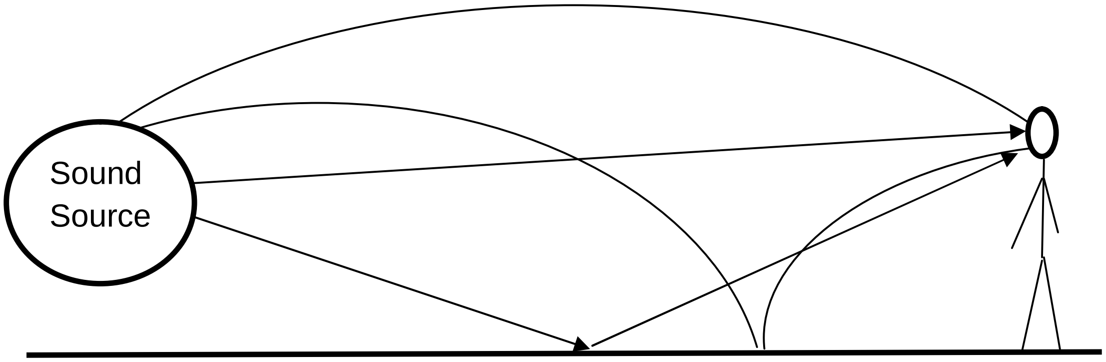

Figure 2: Schematic illustrating propagation paths from source to listener

As illustrated in figure 2 sound transmitted from a power generating station to a point of reception generally travels more or less parallel to the ground. Most surfaces do absorb sound and some acoustic energy is lost to the ground. The underlying physical models are somewhat complicated. Ground absorption is usually treated with an engineering model based on an amalgam of field measurements. Wind and temperature gradients distort the straight-forward 'line-of-sight' propagation path. The phenomenon is similar to the smearing out of the image of a distance object on a hot day. Because of the large temporal and spatial variability of the atmosphere, this effect is described by means of empirical models. The ISO Standard 9613-2 is one of them. The standard prescribes a means of predicting sound pressure levels outdoors.

The levels are representative of "adverse propagation conditions", that is the listener is downwind of the source and there is an inversion layer. Under up-wind and lapse conditions the sound pressure levels tend to be about 3 to 6 dB lower. Finally, atmospheric turbulence acts a time-varying acoustic lens, concentrating or diffusing sound energy. As a consequence, sound levels are never truly steady, even if the source is. These temporal changes are of the order of +/- 2 to 3 dB and are not considered in the assessment process.

4 Sound Level Prediction (Simple Model)

The above formalism can now be used to predict the noise impact from a power generating station. Once the overall sound power level of the plant is specified, the sound pressure levels at any location can be determined. For the example discussed here, the ground is assumed to be level. As a single data point describes the plant, the predicted sound pressure levels are concentric circles centered on the virtual origin of the source (Figure 3).

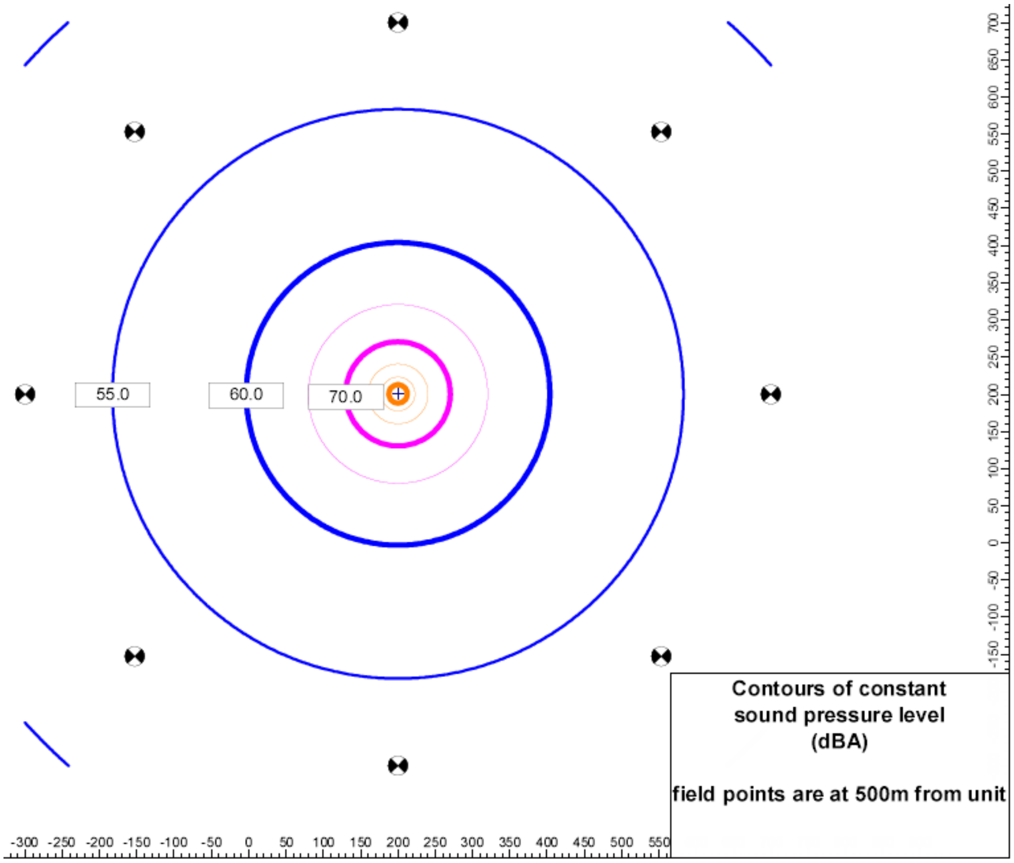

Figure 3: Isobars for a simple sound source with sound power level of 116 dBA.

5 Sound Level Prediction (Detailed Model)

A typical power generating station is made up of many principal components. Each element emits sound with different spectral contents and sound power. Typically the exhaust is characterized by intense low frequency rumble whereas sound emitted by the air inlet may be dominated by high frequency compressor tones. In addition, most sources do not radiate sound uniformly in all directions. All these features are not accounted for in a single lumped point source model. Today most acoustical consultants use specialized sound prediction software that implements the ISO-9613-2 standard.

These computer programs are relatively easy to use and permit one to generate a detailed source model with a little extra effort.

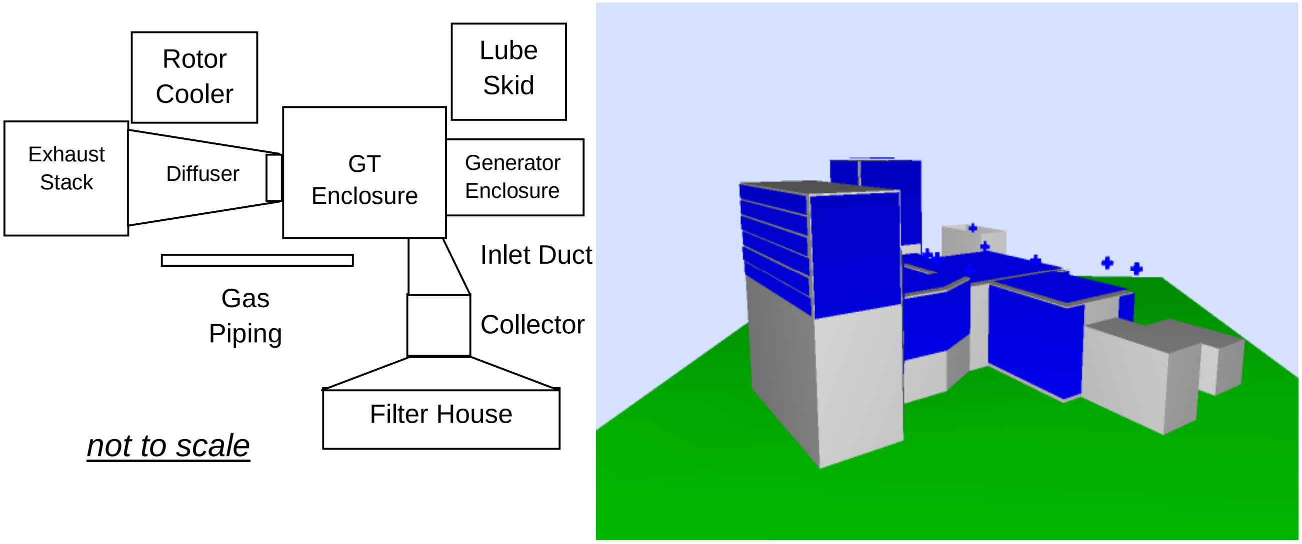

Figure 4: Schematic and 3D image of a generic GT power generating station

If one replaces the single source with a collection of sources, the fidelity of the prediction will be improved. This is illustrated in figure 4 for a generic simple cycle GT power generating station. The sound power levels of the principal elements are summarized in Table 1. The sound power level of each element has been taken from our in-house data base, but can be refined to reflect acoustic data for a specific machine.

Table 1: Sound power levels for principal components.

Source ID	Octave Band Sound Power Levels (dB re 1pW)									*A*
	31.5	***63***	***125***	***250***	***500***	***1k***	***2k***	***4k***	***8k***	
STACK	135	123	123	118	109	96	89	104	101	114
STACKWALL	122	117	107	104	99	100	94	94	78	104
DIFFUSER	117	112	105	105	102	98	94	94	76	104
FLEX CONNECTOR	117	112	105	105	102	98	94	94	76	104
GT WALL	109	117	107	96	89	87	88	85	76	97
GTWALL	93	94	86	77	70	74	75	67	57	80
INLET DUCT	102	101	101	90	81	88	77	80	84	92
FILTER FACE	112	106	97	81	62	66	60	68	74	85
LUBESKID	99	102	100	100	100	100	101	98	91	106
LUBEFAN	110	104	101	98	97	93	101	88	80	104
ROTOR FAN	107	111	102	96	94	89	85	83	79	96
VENTA	89	95	84	80	73	71	76	77	83	85
VENTB	91	96	88	84	75	74	74	73	78	83
GASPIPING	104	100	89	81	80	86	88	91	89	96

Sound is radiated from the surfaces or openings of these elements. Most of the sources are modeled as area sources. For elements such as gas piping, line sources are more appropriate. The building envelope provides for shielding. For example, the inlet filter house tends to radiate most of the sound in the direction normal to the inlet face.

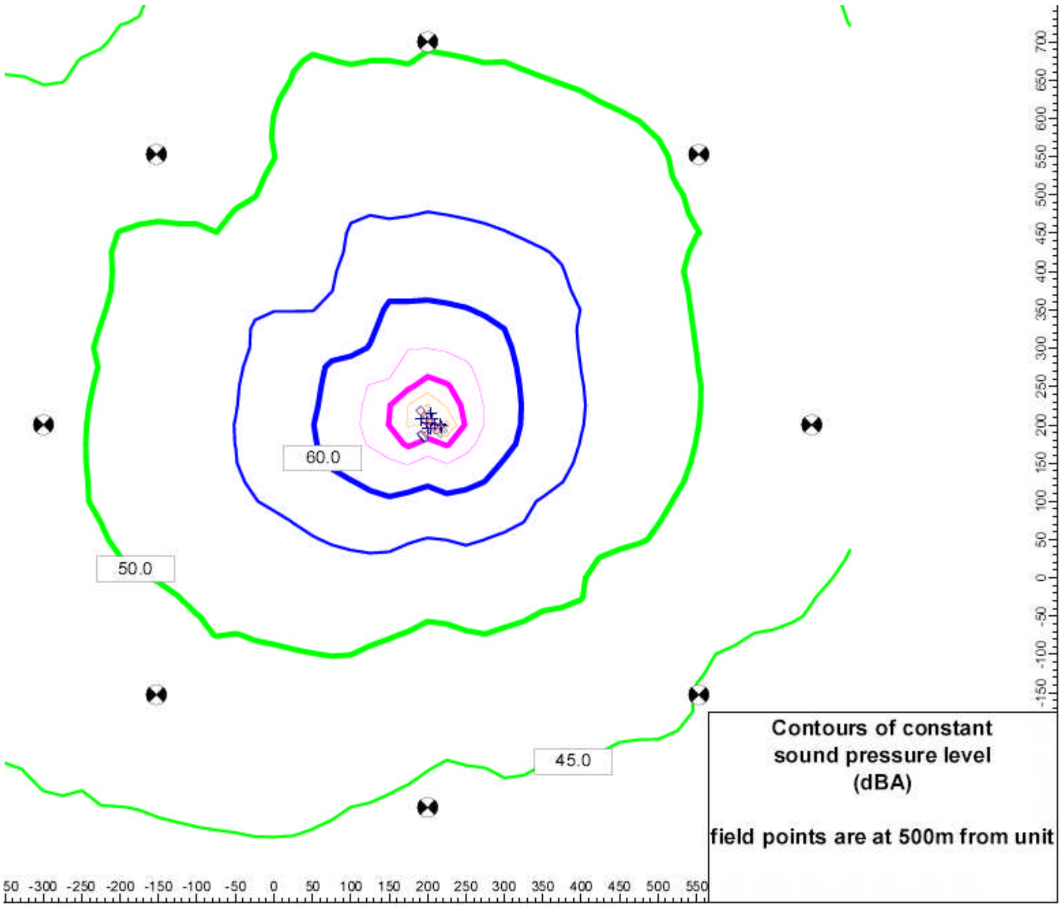

Figure 5: Contours of constant sound pressure level for a realistic GT model

This relatively coarse level of source detail is sufficient to change the predicted isobars from concentric circles into more complex patterns. As is seen in Figure 5, the sound field is not longer homogeneous. There are areas of relative quiet and others where sound levels tend to be somewhat elevated. Table 2 compares the predicted sound pressure levels for field points equidistant from the geometric centre of the GT power generating station with those for a single point source of equal overall acoustic power.

Table 2: Predicted SPL at 500 m from GT power generating station

	FP1	FP2	FP3	FP4	FP5	FP6	FP7	FP8
Simple source model	52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2
Detailed source model	49.1	46.7	44.8	44.1	47.9	48.9	47.4	49.8
Level difference	3.1	5.5	7.4	8.1	4.3	3.3	4.8	2.4

It is apparent that the sound pressure levels predicted for the detailed model differ significantly from those of the point source. On average the levels for the detailed models are about 5 dBA lower. This is a key result. The lower predicted sound pressure level means less adverse noise impact. In the event that mitigation measures are needed to meet noise level limits, the cost associated with them is likely to be significantly lower.

6 Noise Control Strategies

Unless the plant-listener distances are very large, one can expect some adverse noise impact are the closest points of reception. Means of mitigating these can be addressed during the preliminary planning stages, thereby avoiding unwelcome cost over-runs during the detailed design phase.

For each principal element, or component thereof, one can compute the contribution to the overall sound pressure level at any point of reception. This provides key information about the relative importance of each of the sources. Table 3 compares the data in terms of the % contribution in terms of overall levels.

Table 3: % contribution to far-field sound pressure level from principal components.

	Stack + Exhaust	Diffuser	Flex	GT Encl.	Gen. Encl.	Inlet duct	Collector	Filter Face	Vents	LubeSkid	Rotor Cooler	Gas-Line
% contribution to sound power	58.4	5.5	5.5	5.5	1.1	0.3	0.2	0.4	0.2	19.7	0.9	2.4
% contribution to sound pressure	41.8	19.6	0.3	0.7	2.8	0.9	1.0	0.2	0.2	30.8	1.0	0.6

It is evident that there is not necessarily a one to one correspondence between the sound power of a component and the contribution to the sound pressure level in the far field. For the current configuration the differences are due to shielding. The stack/exhaust component is indeed the dominant source and tends to dominate the far field sound irrespective of listener position.

Although single number descriptors such as the dBA are used in noise impact assessment, they are not very useful in prescribing noise reductions needed to achieve sound level limits at off property points of reception. More detailed information about the spectra is required. An example is shown in figure 6. Here the % contribution to the overall spectrum level at a selected field point is shown for all principal components. The low frequency bands are dominated by the stack. Other sources tend to be more prominent, that is audible, at higher frequencies.

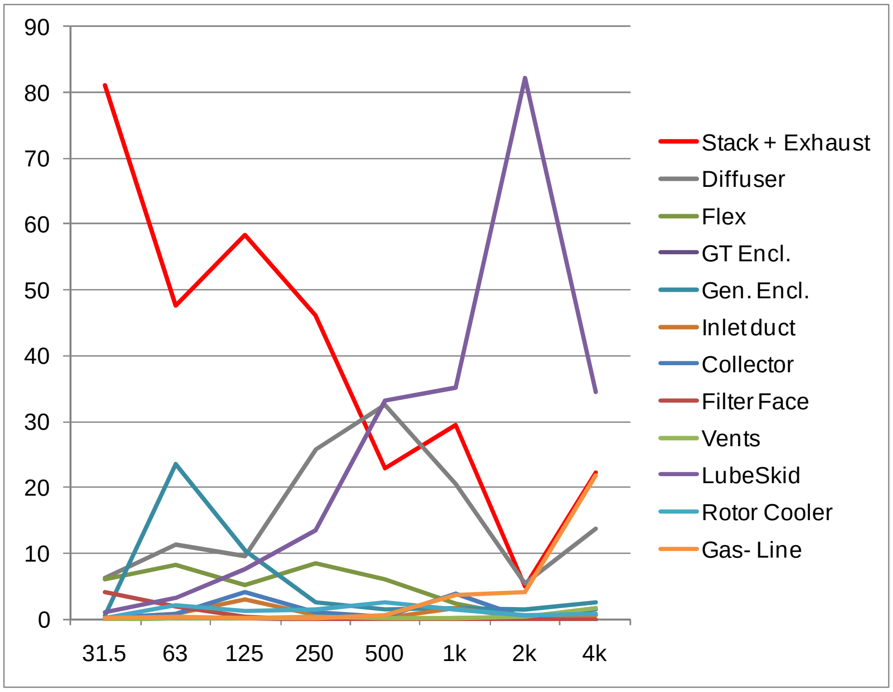

Figure 6: % Contribution from principal components to octave band levels

In order to specify noise controls for a given source, one needs to know the contribution of that source to the sound pressure level. Such a relationships can be described by a 'transfer function' $H_{ij}(f)$, that relates the sound power level of the i^{th} source to the sound pressure level induced by said source at the j^{th} field point:

$$\mathbf{SPL_{i,j}(f)= Lw_i + H_{ij}(f)} \qquad (2)$$

Frequency dependence is indicated by f, the centre frequency of the octave band. These calculations can be performed with the aid of a spreadsheet. The results are then displayed in tabular or graphical form.

Table 4: Transfer Function $H_{ij}(f)$ for a selected field point.

	31.5	63	125	250	500	1k	2k	4k
Stack	70.2	68.8	73.7	74.5	73.4	66.9	69.2	88.4
Diffuser	64.9	65.2	65.4	65.5	65.4	66.0	67.8	79.3
Flex	64.1	64.4	64.1	64.4	64.4	65.1	67.6	78.8
GT Encl.	81.6	88.4	86.3	83.4	83.3	77.8	80.6	97.0
Gen. Encl.	48.6	42.5	45.6	48.8	50.1	57.7	61.5	69.1
Inlet duct	63.8	64.2	64.6	64.7	64.6	65.5	68.7	80.5
Collector	69.2	68.1	65.3	64.1	60.5	60.0	65.8	80.0
Filter Face	51.5	51.3	50.4	50.4	50.6	51.5	54.4	65.7
Vents	66.5	66.2	65.4	63.3	63.5	64.3	67.3	78.6
LubeSkid	67.2	68.4	69.2	71.0	72.1	75.6	73.4	89.9
Rotor Cooler	67.0	69.2	71.9	75.1	78.8	82.9	88.6	102.3
Gas Line	63.0	61.1	61.1	61.0	60.4	60.3	63.3	74.9

The information shown in Table 4 is a key element in the determination of noise controls needed to achieve noise level limits. For when a noise reduction term: $NR_i(f)$ is added to equation (2) the result is the reduced sound pressure level at all field points:

$$\mathbf{SPL_{i,j}(f) = [\ Lw_i - NR_i(f)\ ] + H_{ij}(f)} \qquad (3)$$

One may use embedded programs to determine sound power reductions needed to achieve the sound level limits. The results of such schemes usually results in un-realistic noise control specifications, as the computed performance cannot be achieved by real-world noise control elements. It has been our experience, that a 'trial and error' approach is preferable. Starting with an 'educated guess' a trained noise control engineer can fine-tune the initial estimates in a few iterations. A similar iteration process is also required in the 'fully automated' approach, as the noise control specifications must be adjusted to reflect actual performance.

These calculations are not performed using the specialized acoustic prediction software. The advantage of the interactive approach is that the noise control engineer can examine the effects of noise controls. It also permits one to let clients participate in the noise control process. This is particularly important when noise controls for what appear to be secondary sources must be considered to meet off-property noise limits.

7 Special Cases

The procedure discussed above has addressed sound impact from steady sources, that emit a continuous (broad-band) spectrum. Some sources do not fit this description. They may be tonal, intermittent, or impulsive. As such noises are perceived as more intrusive (annoying), sound level adjustments are recommended by some regulatory agencies. In Ontario for example, 5 dB must be added to the predicted overall sound pressure level, if the sound is 'tonal'.

Determination of 'tonality' requires a more detailed analysis of the sound spectrum. The IEC and ISO standards describe means of identification of tones, and their audibility. These features are not readily implemented in the formalism described herein and must be addressed in the detailed acoustic analysis. Noise emissions that are tonal require special noise controls to reduce their levels to at least 5 dB below the 'broadband' noise. The broad-band noise provides sound masking. For intermittent and impulsive noise the duration and frequency of the signals must be considered. Any noise controls for such sources are usually determined on a case by case basis.

8 Closure

GT power generating stations located in noise sensitive environments require noise controls so that noise emissions are below the allowable sound levels. While it appears obvious that the loudest source will require noise mitigation, assigning noise control priorities is not necessarily straightforward. This is shown graphically in Figure 7, where the ranking with respect to the contribution to sound power is plotted against the ranking with respect to the contribution to sound pressure level.

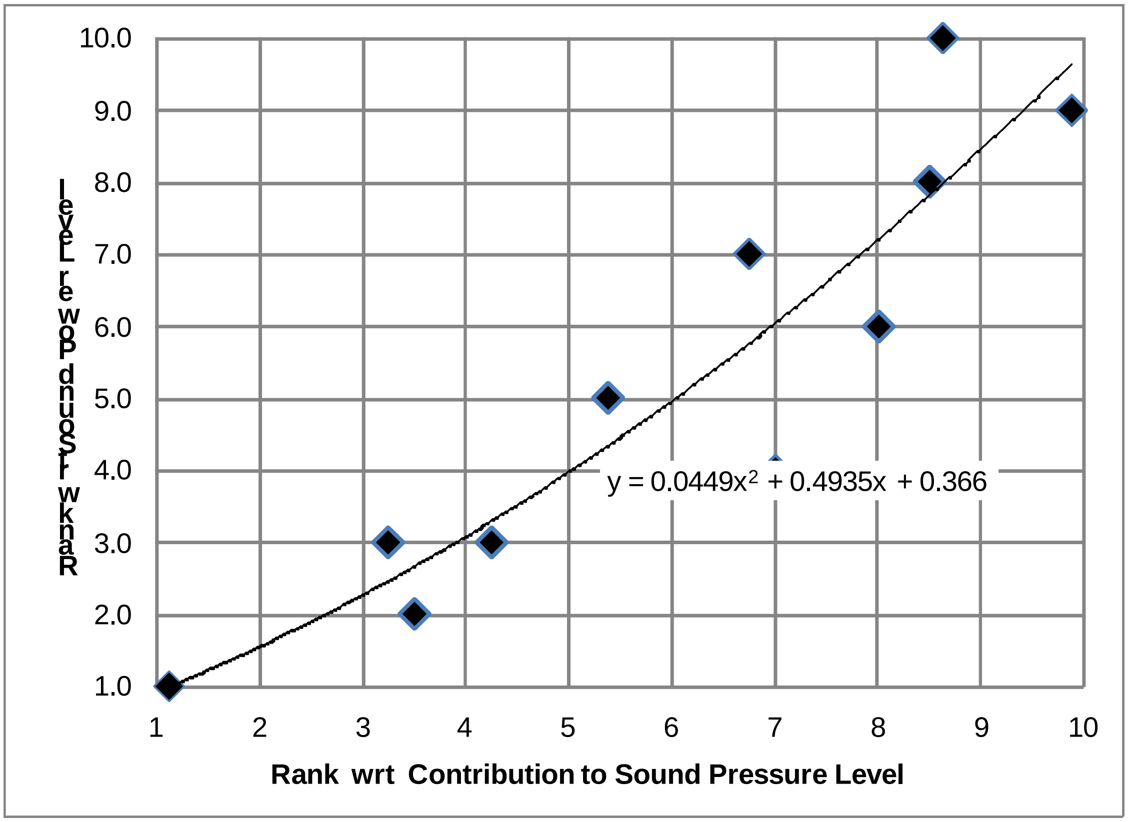

Figure 7: Contribution to far field sound pressure level vs. source sound power level.