Question. 1 *The July 2003 GSI report indicates that the attenuation mode of sound waves becomes cylindrical at a distance equivalent to the water depth below the source. Why did the committee use the intermediate 15 log R in Table 2.3 instead of the spherical (20LogR) and then the cylindical (ie 20 LogR and 10 logR).*

In a perfect loss free medium, with no absorption, refraction, scattering or reflection processes taking place, (ie at the seafloor and sea surface) spherical spreading of a propagating wave takes place until a boundary is encountered. If we assume perfectly loss-free boundaries (a worst case) then at least up to the water depth only spherical spreading takes place. At distances greater than say 3 time the water depth, with loss free boundaries, the propagating wavefront is an expanding cylinder with a theoretical loss of 10 Log R.

A simple propagation model starting at 20 Log R up to a range equal to the water depth, then continuing at 10 log R is very much a worst case.

At short ranges, up to 2x water depth, it does not take into account:

Energy absorption into the seafloor
Energy reflection from the seafloor
Energy scattering at the seafloor
Scattering at the sea surface

At longer ranges, 2 - 10 x water depth, it does not include:

Energy absorbed into the seafloor by multiple reflections,
Scattering processes at both boundaries
Seafloor topography, focussing and de-focussing

At distance ranges >10 x water depth it does not include:

Spreading of the seismic pulse in time due varying path lengths and multiple reflections,
Attenuation of sound due to internal loss processes in the water column, a factor that is also frequency dependent.
Effects of variation in the sound speed with depth due to layering in the water column.

All the processes mentioned above take energy out of the system or redistribute it and therefore allow a decrease in the pressure amplitude of a seismic signature with time and distance from the source. The difficulty in quoting a figure for a particular region is that the local topography, geology, water column structure and wave regime at the surface all vary with time and space. Thus we are forced to generalize or to take examples from actual propagation measurements.

The latter is probably more realistic in terms of absolute levels and it is measurement rather than model data that we have used in estimating the SPL's[1] at several "spot" distances from the source.

If we take measurements made at Sable Island in water depths similar to those in the Gulf of St. Lawrence (Figure 2.10 in Report), the slope of the SPL curve with distance is about 15 log R between 0.1 and 1kM. From 0-100m we must assume this to be about 20 logR. However, beyond 1Km, the curves for all the frequencies shown are steeper at about 18 Log R on average but are about 20 Log R at 10km. Beyond 10km the slope of the curves increase further and are about 40 log R at 30 km.

So really the simple model is very inadequate in practice particularly in shallow water.
Thus the figures given in table 2.3 are based on realistic measurements of propagation loss and are felt to overstate actual values of SPL's.

[1] SPL = Sound Pressure Levels.

Question 2 *Provide the rms values for the GSI source in both vertical and horizontal directions.*

These can only be obtained by having access to actual pressure measurements recorded digitally from the airgun array under test conditions. Often only on-axis[2] data are available and these may not be ideal in terms of the conditions and source receiver geometry for a particular area at shallow angles.

Without actual field data, it is possible to estimate roughly the rms values for a particular seismic impulse on-axis by assuming a certain pulse shape or by re-digitising from a paper drawing. However, both these methods are approximate.

In the attached document, I've estimated that for a typical on-axis air gun pulse will have a rms attribute 5db less that the peak and therefore 11 dB less than the peak - peak attribute. The uncertainty in estimating rms values without the actual data in digital form is due to the identification of the actual duration over which one forms the integration. A figure of 5dB difference will result if the airgun signature is perfectly triangular in form whereas an actual airgun signature (on axis) is more "peaky" in shape resulting in a greater difference between the peak and the rms with the rms being up to 12 dB below the peak attribute.(see Figures 2 and 3 from Canning and Pitt 2002 report attached).

In Table 2.3 I've estimated that the rms attribute is 8 dB lower that the peak value. This is in between the two values quoted above and possible quite reasonable. These comments refer only to on-axis data. Shallow angle data more relevant to horizontal propagation would definitely need actual measurements in order to estimate an rms value for a waveform that is definitely more complex, lower peak amplitude and with a longer duration. Table 2.3 is based on Table 2.1 but the various values adjusted for the proposed power of the GSI airgun array

It may be possible to model an array but off axis calculations are fraught with difficulties. However, modeling is an active research area at the Bedford Institute and various consulting companies in Canada. Several studies are presently underway following seismic testing and monitoring in the Nova Scotia part of the Gulf and reports from these will be released later in the year.

I have requested the information from GSI and will pass it on any relevant information.

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[2] Vertical beneath the centre of an array

Question 3

In table 7.1 of the committee report provide units for rms, SEL, peak - peak) for the various values quoted.

Table 5.1 Estimated threshold values for effects of sound impulses upon fish and cetaceans (assuming spherical spreading of sound; dB values are re. 1 μ Pa @ 1 m)

	PHYSICAL DAMAGE	*BEHAVIOURAL AVOIDANCE*
a) FISH		
Sound intensity	180-220 dB	160-180 dB
Distance from multiple seismic array (248 dB re 1 μPa @1m)	0.25-2.5 km	2.5-25.0 km
Distance from single airgun (226 dB re. 1 μPa @ 1 m)	0.02-0.2 km	0.2-2.0 km
b) BALEEN WHALES		
Sound intensity	?220 dB	130-170 dB
Distance from multiple seismic array (248 dB re. 1 μPa @ 1 m)	0.25 km	7.9-25.0 km
Distance from single airgun (226 dB re. 1 μPa @ 1 m)	0.02 km	0.6-2.0 km

Source: Evans & Nice (1996), derived from values obtained from various studies detailed therein.

Evans, P.G.H., & Nice, H. 1996. *Review of the effects of underwater sound generated by seismic surveys on cetaceans*. Unpublished report to UKOOA. Sea Watch Foundation.

I have contacted Dr. Evans once before about this table as there is an error in the title. It should read:

Table 5.1 Estimated threshold values for effects of sound impulses upon fish and cetaceans (assuming spherical spreading of sound; dB values are re. 1 μ Pa).

There is no direct comment in the document on which attribute was used. But looking at the relevant text I suspect the threshold distances are based on rms values with a directivity factor being included for shallower angles of propagation and for comparison with a threshold level for damage criteria. However I suspect the sound intensity in Column 1 for the air guns are zero-peak pressure attributes as this is mentioned earlier in the text for horizontal propagation.

He also gives a typical source level 0-peak pressure for horizontal propagation of around 230-235 $dB_{0\text{-}p}$ //1 μ Pa@1m . We have used a higher value of 238 $dB_{0\text{-}p}$ //1 μ Pa@1m for the proposed GSI Admiral array in Table 2.3.

I have requested clarification of this table from Dr. Evans. His response may take some time.

More recent data may now be available in this regard. Much work has been undertaken since 1998 and the various distances of perceived effects given in the table above may now be more specifically defined.

Question 4

Below table 7.1, values for corridors for both damage and harassment are proposed. Provide details of the computations with exact units used to obtain the value of less than 200m for physical damage and of about 250m for harassment. Please also indicate the attenuation model used.

This section was compiled by one of the other committee members who may have the original 1996 paper by Evans and Nice. The paper I have which contains this table is a summary paper by Evans 1998.

My interpretation is that for the close distances spherical spreading was assumed with an additional attenuation factor for directional effects. It is to be noted that because of the way the pressure field in the vicinity of an array of sources forms, the reference levels are in fact "notional". They indicate what pressure would theoretically have to be produced by a point source (a single gun) rather than a distributed source such as an array of air guns as is normal practice. In the vicinity of the array, actual pressures would not exceed about twice the peak pressures of a single airgun.[3]

Re-addressing the discussion following Table 7.1 to include the estimates given in tables 2.1 and 2.3 using the stated GSI information for 0-peak (250 dB//1μPa@1m), We estimate that at 1km horizontally, the rms pressure level would be 185 dB//1μPa. The 180 dB $_{rms}$ lower damage threshold would be reached about 2 km which corresponds to the minimum physical damage category for fish in Table 7.1.

I interpret this table as physical damage is likely to occur with a 250m radius of the array and behavioral changes outside that zone. However, the other committee members may have studied other material.

To quote from the text referring to our Table 7.1.

> *" Finally, even if seismic surveys use the lowest practical sound levels, those studies that have been undertaken to date indicate that behavioral avoidance by baleen whales occurs at levels of 160-170 dB which may affect animals anywhere from 0.5 - 8 km distance away.".*

Question 5

Does a safety fact of 2 (doubling the corridor to 500m) is equivalent of accepting a reduced (exposure) targeted noise by a factor of 6dB (assuming 20 log R).

Yes. 20 Log 2/1 = 6 (dB). There is a depth dependancy and also a dependancy on the type of sediment/rock at the seafloor. The sediment cover is important, as softer sediments will remove more acoustic energy from the system. Thus sediment type and thickness will effect how the pressure field will decrease with distance. With simple modeling and sparse information on sediment bottom types and water depth, exact estimations are impossible. However, using spherical spreading up to 2 x the water depth I feel is acceptable and is a worst case situation.

[3] Modelling of the pressure field in the immediate vicinity of an airgun array is a very difficult undertaking. Few groups in the world have the expertise to predict pressure fields and very little ground truth data is available to support the models at close distance. In addition, in terms of long range effects, propagation models are better understood because of the interest of the military. However, the main problem is to predict the amount of acoustic energy that enters the far distant field propagating horizontally. Work is being undertaken by a Halifax based group, JASCO Research, and acousticians at the Bedford Institute of Oceanography on the seismic testing that took place in the Lower Gulf of St. Lawrence in 2003 in the area under Nova Scotia jurisdiction. The results of these studies, when released will greatly help in pressure field estimations as the data were collected at distances within 2 km of an operational seismic survey vessel, In this case the GSI Admiral.

Question 6

In Table 7.2 of the report could you specify the units used and also the intensity of the source (and its units) used for the various regions reported.

This is the original reference from Pierson, M.O. et al, 1998 with some notes that where not included in Tableau 7.2

Table 7.1 Safety zone radii employed during recent seismic surveys

Survey safety zone radius	*Mysticetes*[1]	*Odontocetes*	*Pinnipeds*
Alaska (Beaufort Sea), Northstar, 1997	1,020 m (3,346 ft)[2]	1,020 m (3,346 ft)[2]	260 m (853 ft)[3]
Southern California (Santa Barbara Channel), Santa Ynez Unit, 1995	450 m (1,476 ft)[2]	152 m (500 ft)[3]	152 m (500 ft)[3]
Washington/British Columbia (Puget Sound region), SHIPS, 1998	500 m (1,640 ft)[4]	200 m (656 ft)[5]	100 m (328 ft)[6]
United Kingdom, 1995 to present	500 m (1,640 ft)[7]	500 m (1,640 ft)[7]	500 m (1,640 ft)[7]

Notes:
1 This category includes sperm whales for some surveys
2 The distance at which the received level was estimated to be 180 dB re. 1 μ Pa (rms) for the largest array used
3 The distance at which the received level was estimated to be 190 dB re. 1 μ Pa (rms) for the largest array used
4 An additional 100 m was added to the distance at which the received level was estimated to be 180 dB re. 1 μ Pa (rms)
5 This was twice the distance at which the received level was estimated to be 210 dB re. 1 μ Pa (rms)
6 The distance at which the received level was estimated to be 210 dB re. 1 μ Pa (rms)
7 A distance at which cetaceans may be relatively reliably observed

The units used are rms. Note that Notes 4 and 5 adjust distances so that Tableau 7.2

Tableau 7.2 : Rayons des zones de sécurité utilisées lors de campagnes de levés sismiques récentes en fonction des niveaux sonores jugés acceptables pour les différents projets. ***Measurements are rms values***

Rayon de zone sécuritaire de relevés	Mysticètes	Odontocètes	Pinnipèdes
Alaska, Mer de Beaufort (Northstar, 1997)	1 020 m 180 dB re.1μPa/1m	1020 m 180 dB re.1μPa/1m	260 m 190 dB re.1μPa/1m
Sud Californie (Chenal de Santa-Barbara) Santa Ynes Unit, 1995	450 m 180 dB re.1μPa/1m	152 m 190 dB re.1μPa/1m	152 m 190 dB re.1μPa/1m
Washington/B.C. (Région du détroit de Puget) SHIPS, 1998	500 m [4] 180 dB re.1μPa/1m	200 m [5] 210 dB re.1μPa/1m	100 m 210 dB re.1μPa/1m

Source : (Pierson et al, 1998)

4 *An additional 100m was added to the distance at which the received level was estimated to be 180 dB $_{rms}$//1 μPa*

5 *This was twice the distance at which the received level was estimated to be 210 dB dB $_{rms}$//1 μPa.*

The source levels are not given but I would suggest that a pressure of 255 - 260 dB//1μPa $_{p\text{-}p}$@1m , slightly higher than the proposed GSI admiral array proposed for the Gulf surveys.

Question 7

The committee uses spectral analysis of the frequency bandwidth generated by the GSI airguns instead of the rms to set both damage and harassment corridors. The literature as well as DFO often retains rms units, Explain?

The information given in Table 2.3 compares various attributes in dB notation for a typical airgun array with estimates for near horizontal propagation at -10 degree. It is noted that decibel levels provided in column 1 are equivalent to using the spectral peak of 214.1dB//1uPa^2/Hz . This should have been repeated in the discussion following Table 7.1.

Table 7.1 gives the peak values for the air guns. Please see my response to Q 3.

I agree that the comments below Figure 7.1 are confusing and should be qualified.
The sentence:- "A titre d'example - .... 214 dB." could be misconstrued. This is a comparison of a spectrum peak level and pressure peak that is incorrect. The 214 dB figure refers to the maximum value of the Power Spectrum of the airgun pulse on axis as provided by GSI. See attachment.

Personally I prefer rms figures for comparison purposes but Dr. Long wanted to stress the spectral information.

I feel that 0-peak or rms attributes have been used in the discussions of the various tables.

Attachment 1

From Environmental Assessment Report, GSI Gulf of St. Lawrence M/V Admiral, prepared by Canning and Pitt Nov 2002. This shows the peak-peak pressure of 75 bm == 257.5 dB//1µPa@1m == 0-Peak pressure of 251 dB//1µPa@1m. When converted as a spectrum the peak of the spectrum is quoted as 214 dB//1µPa/Hz$^{1/2}$@1m.

6. Survey Vessel and Energy Source

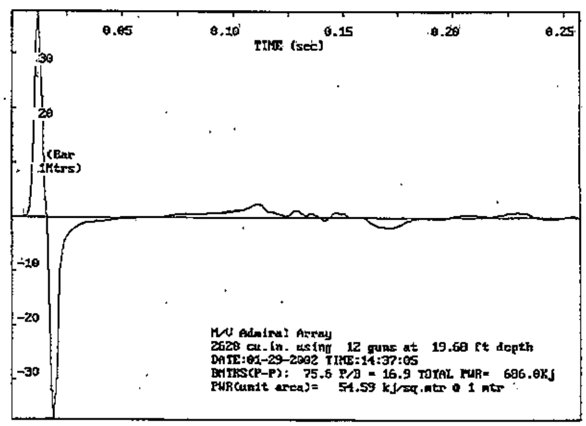
6.1 Survey Vessel and Streamer

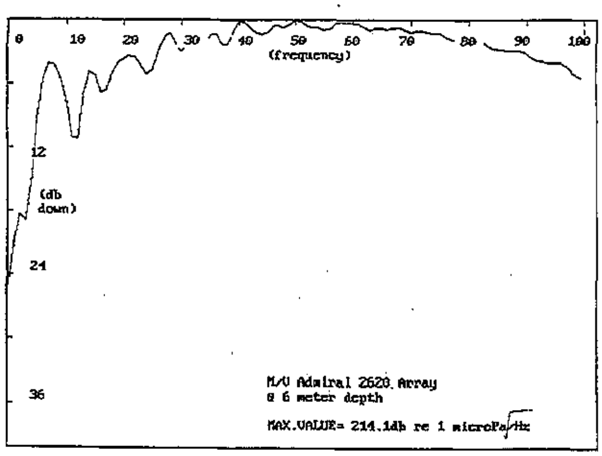
The *GSI Admiral*, a Canadian flag vessel registered in Halifax, will conduct the survey. This vessel is fully equipped to conduct the proposed seismic program. The vessel has in place a shipboard oil pollution emergency plan (SOPEP) in conformity with the International Maritime Organization (IMO) and approved by the Det Norske Veritas Classification AS on behalf of the Government of Canada. On-board environmental protection equipment includes containment booms, absorbent pads, oil spill dispersant, and other such equipment (see section 14.4 for details). The ship is also outfitted with a sewage treatment plant.

The proposed survey will use a single streamer 4,000m in length, towed at a depth of 8m to 9m. It will be a short-section (100m segments) streamer, marked at the end by a tail buoy with a Racal RGPS geopad positioning device, a white strobe light and a radar reflector. Distance from the stem of the vessel to the tail buoy will be approximately 4,200m based on the planned near trace offset, tail stretch and tail rope length. It is expected that the vessel will travel at a speed of 4-5 kts while surveying.

6.2 Source Array

The energy source will be a 2,620 cu.in. / 1900 nominal psi array made up of 12 guns in two sub-arrays. It is expected to have a 75.6 barmeter peak-to-peak pressure with a rise time of 12ms. The source array will be deployed at a depth of 6 metres, and will discharge about every 8 seconds, or 25m. Maximum amplitude will be 214.1 dB re 1µPa at 1m (see Figs 2,3).





Figures 2 and 3