ITU/SMPTE Tutorials on DTTB Appearing in *Journal*

This is the third in a series of edited versions of papers presented at the ITU/SMPTE Digital Terrestrial Television Broadcasting (DTTB) Tutorial Workshop, held in conjunction with the 135th SMPTE Technical Conference in Los Angeles, on October 29 and November 1, 1993. The first articles, which appeared in the May issue of the *Journal*, were: "An Overview of the DTTB Model," by S. N. Baron (NBC, U.S.); and "Video Compression Techniques and Multilevel Approaches," by Marzio Barbero and Mario Stroppiana (Radiotelevisione Italia). In June, the articles were "MPEG Overview," by Stan Baron (NBC, U.S.) and W. Robin Wilson (Grass Valley Group, U.S.); "The Service Multiplex," by Gary Tonge (ITC, England); and "Encipherment and Conditional Access," by Louis Claude Guillou and Jean-Luc Giachetti (CCET, France). Additional articles are scheduled to appear in the next several issues of the *Journal*. A complete volume, *ITU/SMPTE Tutorial Digital Terrestrial Television Broadcasting (DTTB)*, containing all of the papers presented at the tutorial workshop, is available from the Book Department at SMPTE Headquarters.

Planning Factors and Their Influence on System Aspects

By Jorgen Weber

Introducing new radio services or enhancing current ones is dependent on the ability of the service to coexist with other services. Introduction of digital TV must also respect other services and international agreements concerning the use of spectrum. In some countries digital terrestrial TV will be introduced as improvements to existing services, and new spectrum is not likely to be made available. This may even be true where the digital TV system is used for new services, because TV broadcasting is seen by many regulators as spectrum-inefficient and because no free spectrum is available. As a consequence, we have to face the fact that digital terrestrial TV must be able to coexist with present TV services in shared bands. This article discusses the questions related to introduction of digital terrestrial TV and, in particular, the possible trade-offs that will be necessary to make the service work. Will we accept slightly reduced quality in the analog service? What is the noise figure of new receivers? Should it be scalable? Can it be portable? What is the power range? Can it use adjacent channels? Other questions should be: Is a worldwide scenario possible? Are the constraints the same all over the world? Are the trade-offs equally acceptable anywhere? Yet another will ask if one modulation scheme is superior to another, and must it carry HDTV from the start or would standard or enhanced definition do? There are questions about coverage, graceful degradation, service availability, and so on. Factors affecting the planning process are also discussed.

The successful introduction of digital terrestrial television broadcasting (DTTB) will depend on many factors, ranging from commercial to purely technical ones. This article intends to show that this success will also be influenced by choices made in connection with frequency planning. The choices to be made include picture quality, expected receiving conditions, and effects on the current analog services. Many of these choices may be of a subjective character, although closely related to the laws of physics.

The examples given are closely linked to present system implementations and the radio environment around Copenhagen, Denmark. No specific system is mentioned, since this article does not aim to give a full comparative analysis, and because implementations as reflected in CCIR documentation from 1992 cannot be expected to be optimal. The radio environment around Copenhagen has not been chosen because it is hostile (others are even more difficult), but because the data base of frequency allocations used refers to this area.

Likely Conditions for Planning DTTB

The situation, to the author's knowledge, is quite clear in the U.S., where DTTB will be an enhancement of the existing NTSC service, and for a number of reasons no new spectrum is likely to be made available. This is also the case in Europe, although DTTB will not necessarily be used as an extension of the PAL service, but as a new service, at least in some countries. The reason given for not allocating new spectrum is that broadcast already occupies enough of the bands below 1 GHz and that analog TV is not very spectrum-efficient.

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Table 1

Protection ratios:		As wanted (system):		
	Analog 2)	1 and 2	3	4
As interferer (system):				
Analog	42/35	-3	5	7
1 and 2	42/35	10 to 15		
3	42/35		20	
4	42/35			25
2) Grade 4 / Grade 3.				

The conclusion, therefore, seems to be that DTTB must be able to coexist with analog TV in shared bands in America as well as Europe.

Present Environment

Analog TV, as used in North America and Europe, is implemented according to very different procedures and cultures. By simply looking at the distribution of the population one would guess that differences could occur. The North American population is 5 to 10 times less dense than in Europe, and there is a great number of very large cities, so it may be expected that while area coverage may be necessary for at least a number of the channels in Europe, this will not be the case in North America, where population coverage is probably a better measure.

In Western Europe, where frequency usage is intense due to the very high average population density, the planning of DTTB generally becomes difficult. In North America, one would expect the situation to be at least as difficult in some areas, but in general very much easier than in Europe. The number of countries in Europe adds further to these complications, since frequencies are allocated on the basis of multilateral international agreement. Unfortunately, both American and European problems will occur in areas where the population density is very high.

Looking at the test results published about the American advanced television (ATV) systems, one would expect that stations not getting full ATV coverage are located in specific geographical regions rather than being evenly distributed over the continent.

Terminology

Often the terminology used around the world is not the same. For readers of this article this may be confusing, but two things are independent of the terms used: the laws of physics are the same, and the conclusions made here will be general in their nature.

Protection Ratios

Looking at present implementations of DTTB, we find that figures for protection ratios fall in the range shown in Table 1. The figures are dependent on factors such as the number of stages in the modulation scheme used and also the extent to which error correction is applied. The modulation method (single, dual .... multicarrier) will also affect the result to some extent, as will the nature of synchronization, etc.

One immediate conclusion can be drawn from Table 1: namely, that it will have to be decided whether picture quality or protection against interference is more important. The optimum may depend on where the system is to be used and a large degree of flexibility will probably have to be accepted, allowing one implementation in, for example, Copenhagen and another in the triangle between Germany, France, and Switzerland, where the frequency situation is very severe.

Receiver Noise Figure

The receiver noise figure will play another important role. Tables 2 and 3 show an assumed European and American situation with receiver bandwidths of 7.5 and 5.75 MHz, respectively, with a noise figure of 5 dB for the European system and 10 dB for the American. The minimum field strength will be 4 dB higher in America, even if the bandwidth is smaller.

The noise figure of 5 dB is believed to be feasible in Europe, while lower figures will not be

Table 2

European channel				
System	1	2	3	4
Estimated video bitrate [Mbit/s]	5 to 10	10 to 15	15 to 25	> 25
Gracefull degradation	optional	optional	optional	optional
Reconfigurability	not possible	optional	optional	optional
Receiver noise figure [dB]	5	5	5	5
Receiver noise temperature [K]	293	293	293	293
Input impedance [Ohm]	75	75	75	75
Bandwith [MHz]	7,5	7,5	7,5	7,5
Frequency [MHz]	800	800	800	800
Boltzmann's constant	1,37E-23	1,37E-23	1,37E-23	1,37E-23
C/N for system [dB]	6	14	20	26
Receiver noise [dB]	9	9	9	9
Antenna conversion factor [dB]	24	24	24	24
Feederloss [dB]	5	5	5	5
Antenna gain [dB]	12	12	12	12
Minimum fieldstrength [dBuV/m] 1)	**32**	**40**	**46**	**52**
Power flux density [dBW/m*m]	-114	-106	-100	-94
Fieldstrength difference to PAL	39	31	25	19
1) The minimum fieldstrength is chosen to ease comparison to analog TV				

Table 3

American channel				
System	1	2	3	4
Receiver noise figure [dB]	10	10	10	10
Receiver noise temperature [K]	293	293	293	293
Input impedance [Ohm]	75	75	75	75
Bandwith [MHz]	5,75	5,75	5,75	5,75
Frequency [MHz]	800	800	800	800
Boltzmann's constant	1,37E-23	1,37E-23	1,37E-23	1,37E-23
C/N for system [dB]	6	14	20	26
Receiver noise [dB]	12	12	12	12
Antenna conversion factor [dB]	24	24	24	24
Feederloss [dB]	5	5	5	5
Antenna gain [dB]	12	12	12	12
Minimum fieldstrength [dBuV/m] 1)	**36**	**44**	**50**	**56**
Power flux density [dBW/m*m]	-110	-102	-96	-90
1) The minimum fieldstrength is chosen to ease comparison to analog TV				

Table 4

Comparison of the interference effect from vertical polarised DTTB services.

Wanted station	Distance to DTTB transmitter [km]	Coverage without disturbance from DTTB [km]	Coverage with disturbance from 600 W ERP DTTB [km]	Coverage with disturbance from 6 kW DTTB [km]	Coverage with disturbance from 60 kW DTTB [km]	Reduction of coverage area for 6 kW DTTB [%]	Reduction of coverage area for 60 kW DTTB [%]
1 (D)	229	18	18	18	18	0	0
2 (D)	315	35	35	35	35	1	3
3 (DNK)	112	24	24	23	20	4	28
4 (NOR)	422	51	51	51	51	0	0
5 (NOR)	383	71	71	71	70	1	3
6 (S)	216	63	63	62	58	2	13

The analog service is horisontal

Table 5

Comparison of the interference effect from horisontal polarised DTTB services.

Wanted station	Distance to DTTB transmitter [km]	Coverage without disturbance from DTTB [km]	Coverage with disturbance from 600 W ERP DTTB [km]	Coverage with disturbance from 6 kW DTTB [km]	Reduction of coverage area for 600 W DTTB [%]	Reduction of coverage area for 6 kW DTTB [%]
1 (D)	229	18	18	18	0	0
2 (D)	315	35	35	35	0	1
3 (DNK)	112	24	24	22	1	16
4 (NOR)	422	19	19	19	0	3
5 (NOR)	383	71	71	71	0	2
6 (S)	216	63	62	61	4	7

The analog service is horesontal.

achievable until the existing analog services have been closed, because selectivity is needed in the DTTB receiver to exclude interference from adjacent analog transmitters. As a consequence of shared bands with analog TV, noise figures as learned from satellite receivers cannot be expected to be achieved.

The minimum field strength for DTTB will depend on a number of factors, including the receiver noise figure. Interference to analog TV will therefore also be dependent on hardware constraints in the DTTB system setting a lower limit to the effective radiated power (ERP).

Polarization of Signals

If we compare the effect of one digital transmitter in Copenhagen with a number of co-channel transmitters, as shown in Tables 4 and 5, the benefits of using orthogonal polarization for DTTB become clear.

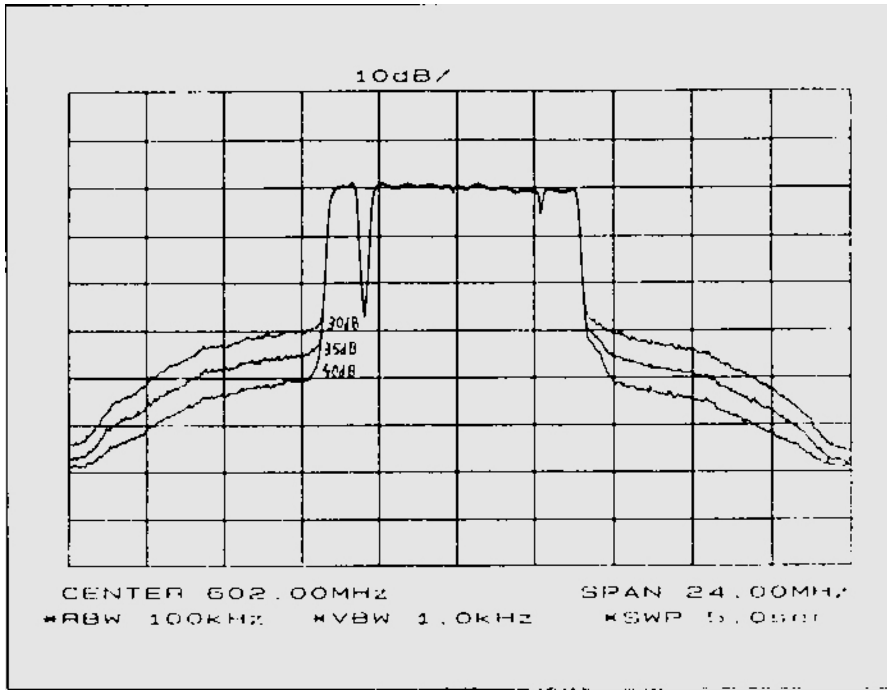


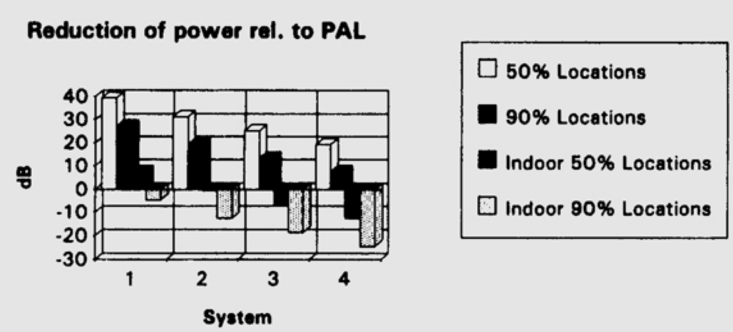
Figure 1. Intermodulation spectrum for an OFDM signal.

Table 6

Coverage of different services at Copenhagen.							
The digital service is using vertical polarisation. PAL uses horizontal.							
	Rooftop (50% locations) good conditions.	**Rooftop (90% locations) good conditions.**	**Indoor good conditions.**	**Rooftop (90% locations) average condition**	**Rooftop (90% locations) poort conditions.**		
600 kW ERP PAL (DR TV) [km]	34						
6 kW System 2 [km]	57	53	18	42	38		
6 kW System 3 [km]	47	45		31	28		
60 kW System 2 [km]	73	68		59	58		
60 kW System 3 [km]	60	58		45	42		
600 W System 2 [km]	44	40		28	26		
600 W System 3 [km]	36	32		19	19		

Table 7

Relative fieldstrength reduction compared to PAL (noise limited)				
System	1	2	3	4
f(50,50)	39	31	25	19
If 90% location	27	19	13	7
If indoor 50% location	7	-1	-7	-13
If indoor 90% location	-5	-13	-19	-25
Necessary ERP (dBk) to mach 600 kW PAL transmitter coverage (noise limited)				
f(50,50)	-11	-3	3	9
If 90% location	1	9	15	21
If indoor 50% location	21	29	35	41
If indoor 90% location	33	41	47	53



The penalty is that it will not be possible to use the same transmitting and receiving antennas for the old analog and the DTTB service.

The conclusion is that one will have to choose either to limit costs in connection with the antenna equipment or the mutual interference between DTTB and analog TV. If the mutual interference is increased, the consequence is that the coverage area for DTTB will be smaller or the robustness of the system must be higher, involving more error protection and giving less room for payload in terms of video quality.

What About Analog Service?

It can also be seen from Tables 4 and 5 that the digital service will affect some of the neighboring analog stations. The stations investigated all lie within about 180 miles (300 km) from the disturbing DTTB transmitter. The frequency plans will formally allow neighboring countries to reject any new station giving increased disturbance to any station in the plan. In practice some increase is often accepted; the question is how much DTTB disturbance can be agreed upon.

In North America, although regulations are very different from Europe, the same question is relevant. The acceptance of increased interference into analog TV will probably be linked to the possibility for the program provider to enhance his own service, leading to the requirement for simulcast and hence many frequencies for DTTB.

Table 4 shows that, for a vertically polarized DTTB transmitter in Copenhagen disturbing horizontally polarized analog transmitters, an ERP of 600 W will be fully acceptable. This ERP corresponds to a reduction of 30 dB compared with analog TV. With an increase in power to 6 kW, the disturbances reduce the coverage of the nearest transmitters by less than 5%, which may be accepted, while reductions up to 30%, as seen for 60 kW, will definitely not be tolerated. A similar analysis for horizontally polarized DTTB, shown in Table 5, will lead to the conclusion that not even 6-kW ERP can be accepted for DTTB.

As for the analyses in Tables 4 and 5, it should be added that analog transmitters with low power were not taken into account and, as a consequence, 12 analog transmitters will have to be reallocated. Furthermore, the calculations were carried out for the most favorable frequency.

It may be concluded that the power allowed for DTTB, as far as interference into analog TV is concerned, will certainly not be higher than -20

Table 8

Fieldstrength relative to f(50,50) in dB				
For minimum fieldstrength at 90% location		12		
For indoor reception:				
Lost antenna gain [dB]	12			
Cable loss [dB]	-5			
Lost hight gain [dB]	10			
Building penetration loss [dB]	15			
Sum for indoor		32		
Indoor at 90% location		44		

dB compared with the ERP of today's analog TV, and in many areas, even -30 dB may be a problem. As we will see, this can influence the choice of a DTTB system.

Concern has been expressed on several occasions concerning DTTB-caused disturbances in adjacent channels. From Fig. 1, which presents the spectrum of a coded orthogonal frequency division multiplex (COFDM) signal passing through an amplifier being overdriven, it can be seen that DTTB will not give rise to severe out-of-channel emission. Reports to the CCIR suggest that co-channel interference will normally be dominant.

What About DTTB Service?

The nature of disturbance to a digital signal is very different from the nature of disturbance to analog TV; this will also be the case where the service area is limited by noise rather than interference. This is due to the relatively abrupt failure of the digital service and to the fact that blocking errors, as often seen on digital pictures, are very annoying. One question that will need an answer is the service area probability, which for current PAL planning in Europe is 50%. Should this be higher for DTTB and, if so, how high? The answer is probably not known, but the general assumption in Europe is that 90% locations will be necessary to overcome these problems.

Table 6 shows a comparison of coverage for DTTB systems and PAL. For a good channel with low interference, coverage of approximately the same area as for PAL can be obtained with 30 dB lower power and System 3 (enhanced to high-definition TV), while for an average channel, -20 dB compared to PAL seems to be just about enough for HD-like picture quality. For the poor channel, System 3 would only cover when using 60-kW ERP, which is known to be impossible. The solution would be to use a system with a lower quality, for example, System 2.

The question will be whether the coverage of DTTB must in any case be similar to that of the analog service. If the answer is yes, different quality grades for various areas must be accepted or, as an alternative, the same low quality accepted all over.

Graceful Degradation, Reconfigurability, or Embedded Quality Levels

Coverage comparable to that of analog TV cannot in all cases be obtained for the quality level desired, and it is therefore necessary to decide how to overcome this problem. A solution will be to have two or more quality levels in the same bit stream, the two bit streams having the quality of Systems 3 and 1, respectively, as its two tiers, with approximately the same protection ratios as these systems, so that the whole coverage area can be covered by at least standard-definition TV (SDTV). In some regions, where the interference is very high, it may even be decided not to broadcast the high level, still having a universal standard. Reconfigurability will mainly affect the number of services in a channel, but since overhead is necessary, full reconfigurability and scalability are probably not to be expected at the same time.

The option just described is a simple case of graceful degradation; more complicated systems could be considered, but this would add to the cost of the equipment.

Portable Indoor Reception

In Table 6, the figure for portable indoor reception shows that not even for System 2 will it be possible to obtain full coverage. The solution could be to accept portability where it works, and possibly to locate the main transmitters close to where the portable receivers are most likely to be used. Another option may be the use of indoor repeaters, although many indications can be found that this will not be possible in Europe.

Dense Networks

As shown previously, full country coverage is difficult to achieve, and even coverage matching the analog transmitters to be gradually replaced by DTTB is hard to obtain. A solution at least providing coverage of populated areas would be the use of dense networks, where the ERP of the digital service is decreased while the number of transmitters is increased. The idea is to use the same

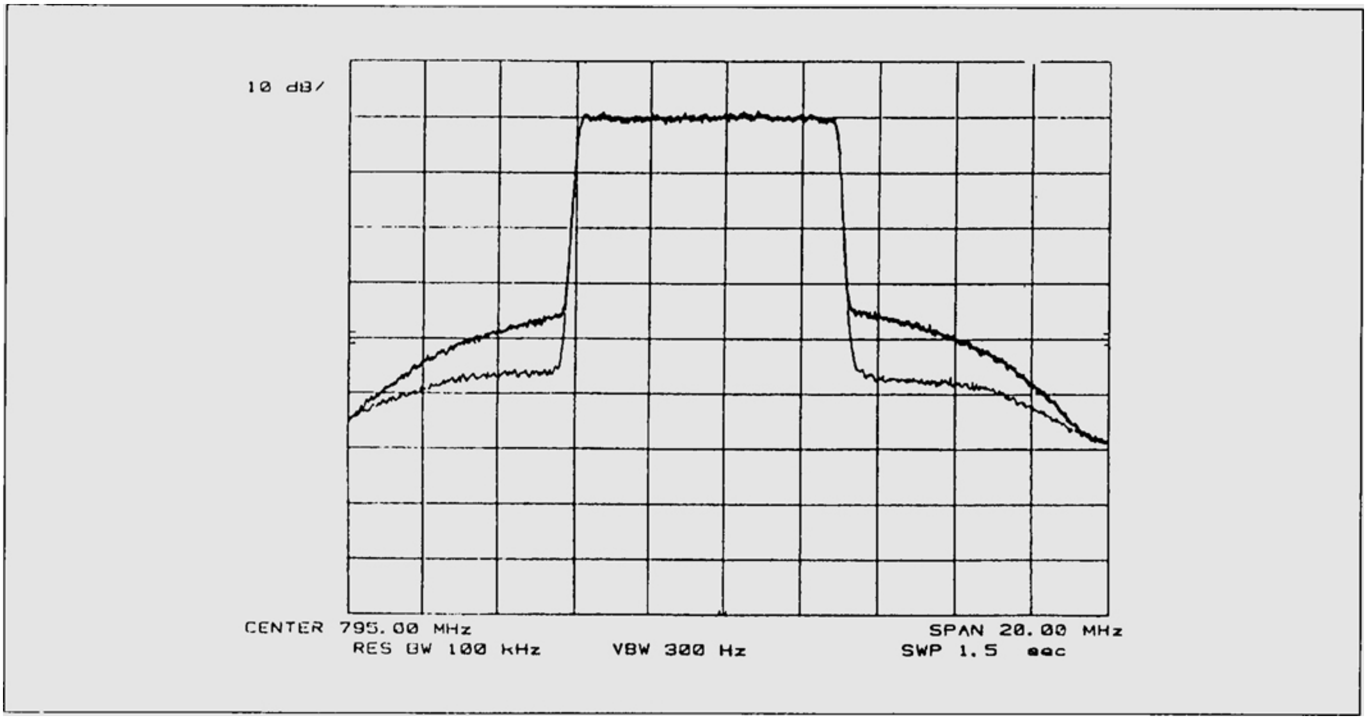


Figure 2. Spectrum for an 800-W transmitter with and without linearity correction.

frequency for all transmitters in a dense network, thus forming a local/regional single-frequency network.

In Europe the experience with digital audio broadcasting (DAB) has led to a very strong interest in such solutions, based on the COFDM technique. Using this multicarrier system with guard intervals, one can obtain frequency, time, and space diversity even if the delayed signals at the receive site are equally strong. The trade-off is to be made between channel capacity and length of the guard interval. Since COFDM is based on FFT and IFFT, this length will also influence the solutions that can be implemented.

Single-Frequency Networks

Single-frequency networks covering more than local or regional areas will not be possible until clear channels can be obtained, simply because no channel is available on a country-wide basis. On the other hand, when this is realized, the possibility of increasing the spectrum efficiency is also open.

In the future, when the UHF channels have been freed from analog TV, approximately 40 channels will be available for DTTB; planned on a block basis, each country will have 10 HDTV possibilities, or at least 40 SDTV.

Sharing a Channel

Instead of having one HDTV program in an 8-MHz channel, it would be possible to have four in SDTV, thus relaxing the requirements in a certain area by a factor of 4. The penalty will be that the multiplex must foresee such an operation.

Possible Solutions

For analog services the following points will have to be considered:

- Will allocations be changed for thousands of low-power analog transmitters? This will be necessary, at least in Europe.
- Will the power of the digital service be reduced to an acceptable level, disregarding the effect on coverage?
- Agreement should be reached on the level of increased interference to analog TV that is acceptable and how the increase should be calculated.

For DTTB the following actions will have to be considered:

- To adapt the ERP to the highest possible level in any area.
- To accept that some areas will have better picture quality than others.
- To accept that the use of polarization discrimination will probably be necessary.
- To accept that the noise figure, when lowered, improves the system performance.
- To develop systems with scalability.
- To introduce the concept of population rather than area coverage.
- To use dense networks where necessary.
- To share one channel between several services; for example, four SDTV rather than one HDTV channel in 8 MHz.
- To forget rabbit-ear antenna reception all over the coverage area, which will require extreme power levels (Table 7).

Finding New Spectrum

The obvious solution might be to find a new spectrum for the DTTB service. This spectrum could be quite efficiently used, since disturbance between DTTB services is low and the option of single-frequency networks is open right from the start.

Conclusion

A number of planning factors affecting the choice of system, as well as the complexity and economy of the DTTB service, have been investigated. No easy solution has been presented, but questions have been raised that require answers.