Considerations for the Design of Future Treaty Monitoring Seismic Arrays
This research started with writing the specifications that were discussed in the early Working Group B (WGB’s) meetings back in the late nineties, coupled with a number of lessons learned in the subsequent decade and a half from the installation of a number of these arrays. Also included were a number of upgrades to then existing arrays, and more recently, improvements in the hardware (for example: hybrid seismometers), communications etc. Lastly, and importantly, what information do we need to acquire from the newer versions soon to be deployed. An important element of this research includes detailing those features of the deployed arrays that have served so well that any new array should take advantage, by starting with these features; thereby, making even greater capabilities in our monitoring capability.

The recent DPRK events have helped in the improved design of the arrays; probably improvement can be summed up in the array design needs to reduce the effect of noise; however, equally important is stressing the character, and number of signals to be detected so that processing such as correlations can be performed. Another important feature is the increased sample rate required in the future.
Background

- Current PTS seismic array design was driven by long-haul communications & installation costs.
- Most new array (1997) configurations included a broadband plus nine short period instruments.
- Existing arrays maintained old configurations:
  - Sample rate: Newer arrays at 40 sps; older arrays at 20 sps.
  - Number of elements: 9 + BB (Some were much larger).
  - Seismometer type: Broadband and short period.
  - Array aperture: Accommodates teleseismic & regional signals
  - Long period arrays: Several AFTAC legacy arrays retained, and suspect that data not used by IDC.

Current seismic array design has been relatively unchanged since the early Working Group B meetings in the late 90s.

At that time, design was taken from GSETT-3, modifying it to enhance detection of regional and teleseismic events.

The array aperture and spacing of the elements was dependent on the signal and noise characteristics at each particular site.

In all cases the requirements were stated to be minimum, and more stringent requirements could be enacted.

Most new arrays built by the PTS, and AFTAC, were built to these minimum requirements; however, TORD was an exception for the IMS.

These arrays are now at the point, or getting to the point, of being upgraded.

So this is an appropriate time to consider major adjustment to the design.
What is new?

Where should the emphasis now be placed?

Detection of signals*, and association of events are currently being accomplished to acceptable levels.

The latest challenge is probably three-fold, that being:
(1) Improved identification of the detected events, and
(2) reduction of analysts’ workload, especially for earthquake swarms.
(3) *Recent events require a lower detection threshold.

Comment: A useful method for improving results is to rely on the numerous events currently existing in our archives.
Current array design is at least fifteen years old, and does not take into account advancements in signal processing, or reduction in long-haul comm costs.

New design should consider short & long period signals

New design should consider the following items:

- Sample rate: Perhaps as high as 200 sps with down sampling capability
- Number of elements: Should NOT be limited to nine or ten
- Seismometer type: Consider hybrid seismometers (BB & SP)
- Array aperture: Should accommodate teleseismic & regional signals (Number of elements should increase as suggested)
- Number of components: Consider use of multiple 3-Cs

Way forward – Utilize lessons learned from design of TORD & recent NORSAR recapitalization
The following specific items should be further explored:

1. Referring to the paper titled “Relative Contribution of IMS Stations to REB of IDC” by John Coyne, Yan Jin and Chip Brogan understand what are the unique features of the seismic array stations (WRA, MKAR, ASAR, TORD, ZALV) that make them such high contributors.

2. Following up on item 1, attempt to separate source and path corrections in order to better understand receiver characteristics that appear to be so beneficial.

3. This paper concludes that contributing factors affecting performance include: Near-Surface geological conditions under the station, STATION NOISE LEVELS, STATION DESIGN, Global distribution of seismicity, and heterogeneties within the earth.

4. IMS auxiliary stations also exhibiting exceptional performance are BVAR, QSPA, AKTO, KURK, and SIV.

- In summary, we suggest that the design of modern seismic array stations may be enhanced by studying the above stations; especially, with respect to the location of the station, the arrangement of the elements, the aperture of the array, and, perhaps the most important feature, the number of elements in the array. Obviously, some of the above desirable features will be difficult, or impossible to optimize in the design; however, one should be aware of them and design accordingly.
Why a Hybrid Seismometer

There are numerous and clear benefits of a Hybrid response seismometer (three are given below):

1. Combination of flat in velocity and acceleration within the pass band of interest provides a reasonable trade off for recording of HF and LF signals.

2. Better utilization of available dynamic range of the recording system hybrid response is good for both high and low frequency signal detection.

3. Compliant with IMS minimum specifications.
3-Component Hybrid Seismometer

CMG-3T Hybrid Response:
(Vault 3 Component Broadband Seismometer)

-- 360 Seconds to 0.33 Hz flat velocity
-- 0.33 Hz to 2.0 Hz flat to Acceleration
-- 2.0 Hz to 50.0 Hz flat to Velocity
  -- Zeros are at -0.333; 0.0; 20.0
-- Poles are at -1.96E-3+1.96E-3j; -1.96E-3 -1.96E-3j; -24+21j; -24-21j;
  -41+114j; -41-114j; -2.0
CMG-3V Hybrid Response:
(Borehole Short Period Vertical Seismometer)

-- 120 Seconds to 0.33 Hz flat velocity
-- 0.33 Hz to 2.0 Hz flat to Acceleration
-- 2.0 Hz to 50.0 Hz flat to Velocity
  -- Zeros are at -0.333; 0.0; 0.0
-- Poles are at -5.89E-3+5.89E-3j; -5.89E-3 - 5.89E-3j; -24+21j; -24+21j;
  -41+114j; -41-114j; -2.0
The following points may be relevant to this presentation:

1. The BURAR seismic station, originally 9 Sp & 1 BB instruments, has an additional 5 BB instruments mounted in vaults. How much has its capability been enhanced?

2. It has been proposed to the PTS that additional Sp instruments be added to the Keskin array to meet minimum requirements. How much would this addition improve that region's IMS capability?

3. If the suggested array changes were incorporated in replacing an existing station, what would the effect be on the cost of installation, operation, and capability of that station, and the overall IMS network? (i.e., when designing a new array, or upgrading an existing array, perhaps a NetSim type simulation should be performed prior to finalizing the design.)
The following reports are also relevant to this presentation:


3. Two proposals on 3-component arrays; one by Wilmer Rivers & Hafidh Ghalib; The second by Ghalib et. Al.