SOME FEATURES OF WAVE FORMS OF SEISMIC EVENTS FROM THE AREAS OF NUCLEAR ASIA TEST SITES ACCORDING TO THE DATA OF AS60 SEISMIC STATION (AAK, «ALA-ARCHA», KYRGYZSTAN)

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A three-component seismic station «Ala-Archa» (AAK) was installed in Kyrgyzstan in May, 1983. It is located in specially constructed granite tunnel away from the seismic noise sources which has made the station an effective site for monitoring both regional, teleseismic events, and nuclear explosions, conducted at the Asia Nuclear Test Sites. In October 1990, a digital broadband seismic station AAK of the IRIS / IDA (GSN) network was installed here, which was included in the IMS CTBTO network as an 3-C auxiliary seismic station AS060, certified in 2007 (Figure 1). It was first digital seismic station in the Kyrgyz territory. In September 1991, one of the stations of the first digital network in Kyrgyzstan, KNET has begun its operation in the same tunnel.

Figure 1. AAK (AS060) station.

Geographically, the AAK station is situated in the North-Tien Shan on the northern slope of the Kirghiz ridge along Bishkek meridian (33 km to south from Bishkek, capital of Kyrgyzstan), φ = 42.638 ° N, λ = 74.494 ° E, at an altitude of 1633 m. The station is located on the border of the Cenezoic Chu Depression to the north and the Pre-Cambrian granites and gneisses of the Kyrgyz Range to the south. The border is a neotectonic one and is characterized by thrust faults, due to ongoing N-S compression. The equipment is in a tunnel cut in the hanging wall of the Chonkurchak border fault and is emplaced in Paleozoic bedrock. The Valley has extensive alluvial deposits.

Seismic equipment is installed on the right-hand bank of the Ala-Archa river at the specially constructed U-type granite tunnel with 100 ×30×100 m size, which is a unique facility for the installation of geophysical devices. The thermal insulation of the tunnel is provided by a system of heat-insulating locks that reliably isolate the internal volume from the external environment. Temperature fluctuations within the tunnel during do not exceed ± 0.25°C during the whole year. Seismic sensors are installed on special concrete bases firmly linked with bedrock, and isolated from external noises. The station building is connected with the tunnel by the help of cable, the length of which is about 300 m (Figure 2).

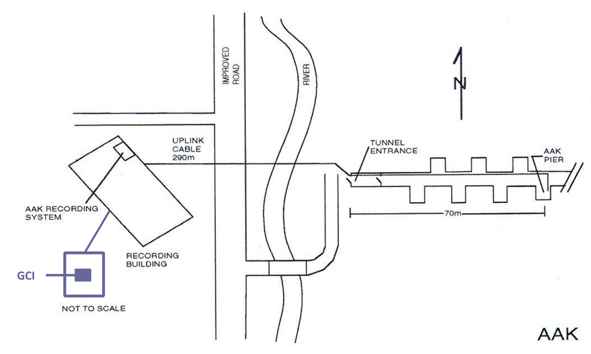

Figure 2. General layout of AS60 station (AAK).

Seismic station AAK (AS060) is a modular system of hardware (Figure 3), which includes:

- Three-component broadband sensor STS-2.
- Three-component short-period sensor GS-13.
- Accelerometer.
- Electronic barometer.
- GPS-based time system.

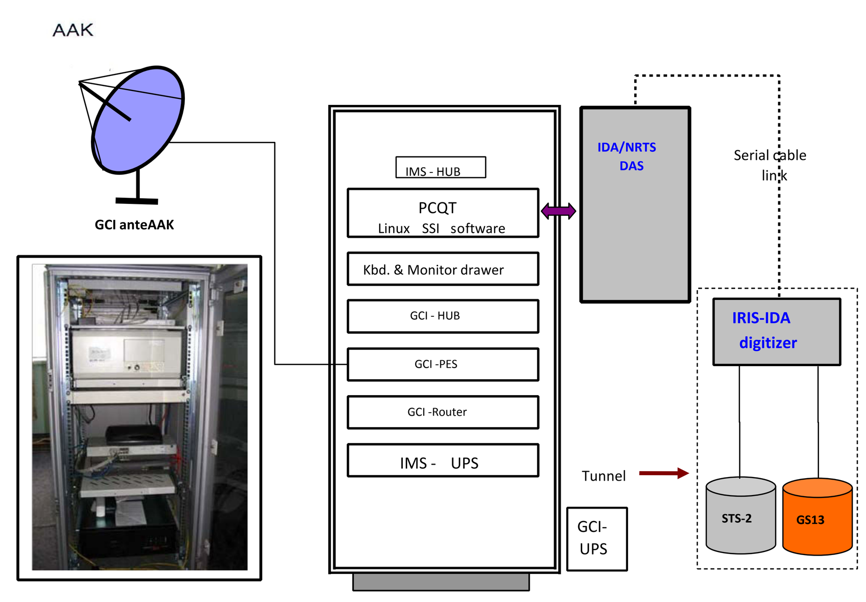

Figure 3. AAK equipment layout.

One of the effective methods for estimation of seismic stations sensitivity is the study of seismic noise based on the station records analysis. There are specific parameters of seismic noise for each station, which include the equipment characteristics, the station location, geological conditions, noise sources remoteness.

Plot of the spectral density (PSD) of seismic noise at the AAK station for the Z component according to the Peterson model [1] is presented on the Figure 4. According to this figure, the AAK station is characterized by noise, close to the world low-level noise model, which ensures its high efficiency in seismic monitoring activity. The level of seismic noise in the daytime practically agrees with the night seismic noise owing to the station remoteness from anthropogenic noises, as well as equipment location in the tunnel.

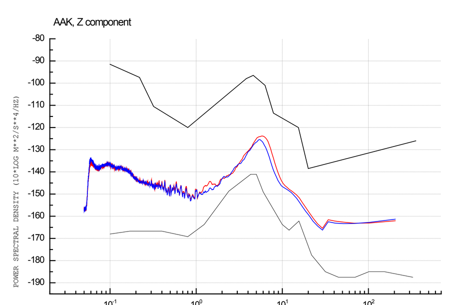

Figure 4. PSD of the AAK station: red curve – noise for daytime; dark blue – night noise.

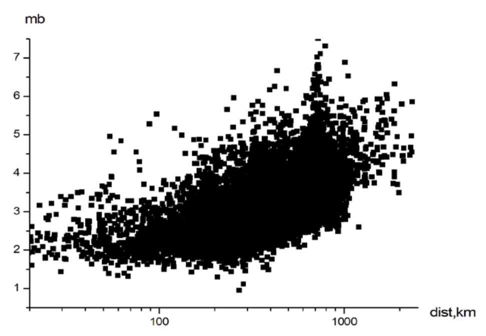

Figure 5. Dependence of mpv magnitude on distance according to the AAK seismic station data.

For estimation of the AAK station range the dependence mpv and distance is plotted, where mpv is a magnitude of the body waves computed using the regional calibration curve. According to the analysis of seismic bulletins of KNDC (IGR, Kazakhstan) and NDC-KG (IS, Kyrgyzstan for 2009-2017) [2] the dependence mpv_{min} and mpv_{comp} (magnitude of completeness) on distance was calculated, namely: up to 1000 km $mpv_{comp} = mpv_{min} + 0.5$, and after 1000 km $mpv_{comp} = mpv_{min} + 0.9$ (Figure 5). Table 1 shows the mpv_{min} and mpv_{comp} values for the AAK station.

Table 1. AAK station range.

Distance, km	AAK	
	mpv_{min}	mpv_{comp}
100	1.6	2.1
200	1.8	2.3
500	2.5	2.8
1000	2.9	3.4

For analysis of the seismic station effectiveness in seismic discrimination purposes, a database of AAK seismic station records of various nature of Asia test sites Lop Nor, Chagay, Pokhran for the period 1991-2017 was created in the CSS3.0 format. So far as at the Semipalatinsk Test Site the nuclear tests were conducted until 1989, and the AAK station began its digital registration since 1990, digitized analogue SKM and SKD seismograms for 1983-1989 period and distance of ± 150 km from the test site center were used for analysis (Figure 6).
For the Punggye-ri Nuclear Test Site (2006-2016), only underground nuclear explosions have been collected, as the test site is situated at the teleseismic distance.
In total, the database contains above 100 seismograms recorded at regional and teleseismic distances for 1983-2017.

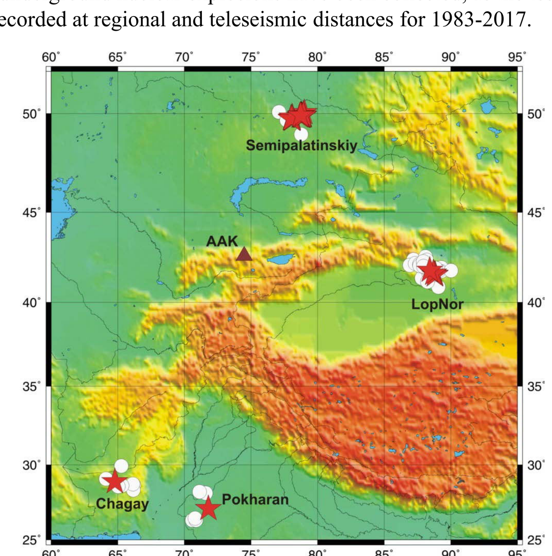

Figure 6. Map of the location of seismic events in the region of Asia test sites, registered by the AAK seismic station at regional distances. Triangles – seismic stations, circles - earthquakes, asterisks – UNEs.

The maximum amplitudes of the main regional phases (Pn, Pg, Sn and Lg) were measured for seismic events at local and regional distances from the areas of Asia test sites. Measurements were made on vertical components of seismograms. The processing technique included measuring the decimal logarithm of the ratios of the maximum amplitudes of the S- and P- waves (Sn/Pn, Sn/Pg, Lg/Pn, Lg/Pg (S/P)) after the narrow-band filtering. Filters with central frequencies of 0.3, 0.6, 1.25, 2.5, 5 Hz and a bandwidth of 2/3 octave were used at -3 dB from the maximum (Figure 7).

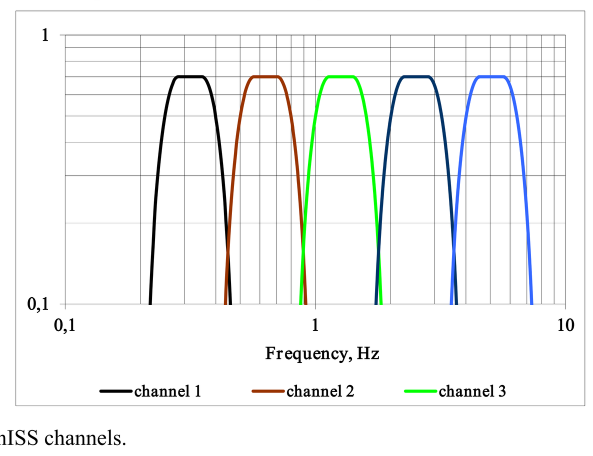

Figure 7. Frequency characteristics of narrow-band ChISS channels.

For the Lop Nor Test Site in China, an area limited to coordinates of 40°- 43° of northern latitude and 86°-91° of eastern longitude was considered. 33 records of earthquakes and UNEs with epicentral distances from 1020 to 1280 km (Figure 8) and magnitudes mb from 4.1 to 6.5 were processed, 6 events from them were UNEs and 27 earthquakes. Figure 9 shows the seismic record of the UNE, conducted on May 15, 1995, t0 = 04:05:57.8, φ=41.60°, λ=88.82°, mb=6.1. The seismogram is characterized by a clear arrival of Pn phase with domination of Pg-phase amplitude, the ratio of Lg/Pg amplitudes is close to 1. Figure 10 demonstrates the distribution of Sn/Pn, Lg/Pn, Sn/Pg, Lg/Pg spectral ratios. A clear separation of their parameters is observed for a filter with a central frequency of 2.5 and 5 Hz.

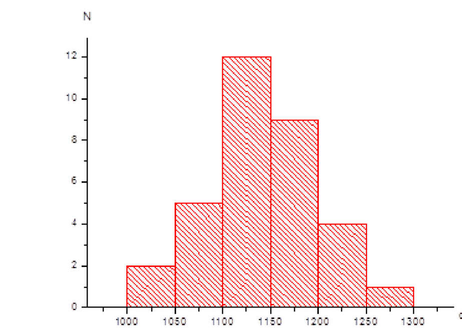

Figure 8. Histogram of epicentral distances distribution.

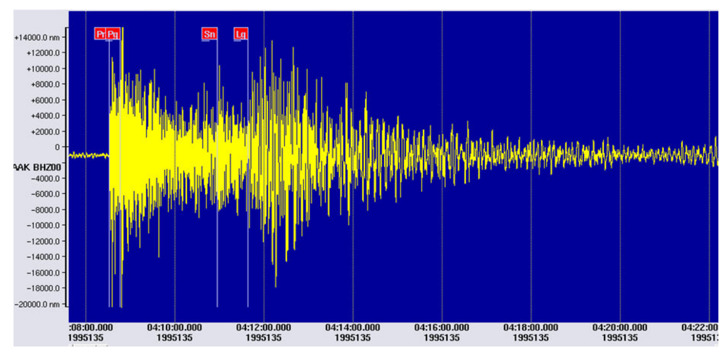

Figure 9. Seismic record of UNE of May 15, 1995, t0=04:05:57.8, φ=41.60°, λ =88.82°, mb=6.1. Z-component.

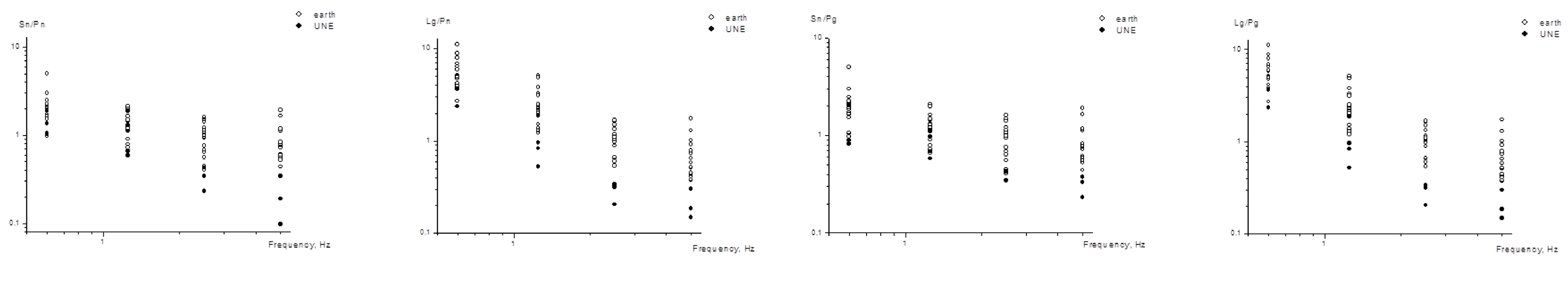

Figure 10. Distribution of spectral ratios of maximum amplitudes of regional seismic phases for the area of the Lop Nor Test Site: (a) Sn/Pn; (b) Lg/Pn; (c) Sn/Pg; (d) Lg/Pg.

For the Indian Test Site, Pokharan, the area bounded by the coordinates of 25.5°-28.5° of northern latitude and 70 ° -72 ° of eastern longitude was considered. Six records of earthquakes and UNE with epicentral distances from 1628 to 1846 km and mb magnitudes from 4.1 to 5.6 were processed, namely, 1 UNE and 5 earthquakes. Figure 11 shows the seismic record of the UNE of May 11, 1998, t0 = 10:13:41.8, φ=27.0716°, λ =71.7612°, mb = 5.2. The seismogram is characterized by a clear arrival of P-phase, domination of the P-wave amplitude, the amplitude ratio
S/P < 1. Figure 12 demonstrates the distribution of S/P spectral ratio. A clear separation of their parameters is observed for a filter with a central frequency of 1.25 and 2.5 Hz.

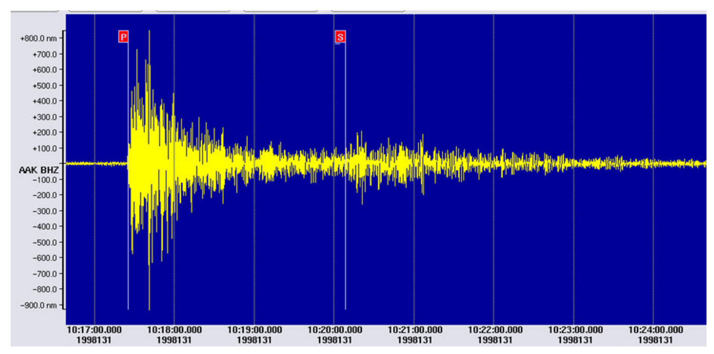

Figure 11. Seismic record of the UNE of May 11, 1998, t0 = 10:13:41.8, φ=27.0716°, λ =71.7612°, mb = 5.2. Z-component.

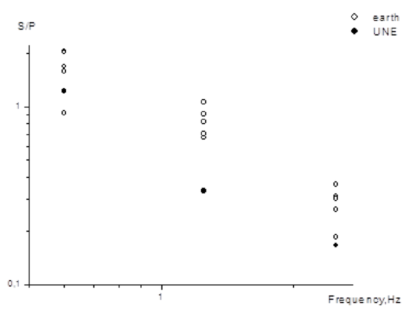

Figure 12. Distribution of the spectral ratio of the S/P maximum amplitudes for the Pokharan Test Site.

For the Semipalatinsk Test Site (STS), the area bounded by coordinates of 48°-51° of northern latitude and 77°-80° of eastern longitude was considered. 28 records of earthquakes and UNEs with epicentral distances from 837 to 878 km and mb magnitudes from 3.7 to 6.1 were processed, namely, 25 UNEs and 3 earthquakes. Figure 13 shows the seismic record of the UNE of October 4, 1989, t0 = 11:30:00.16, φ =49.7498°, λ =78.0117°, mb = 4.7, conducted at the Degelen site (STS).

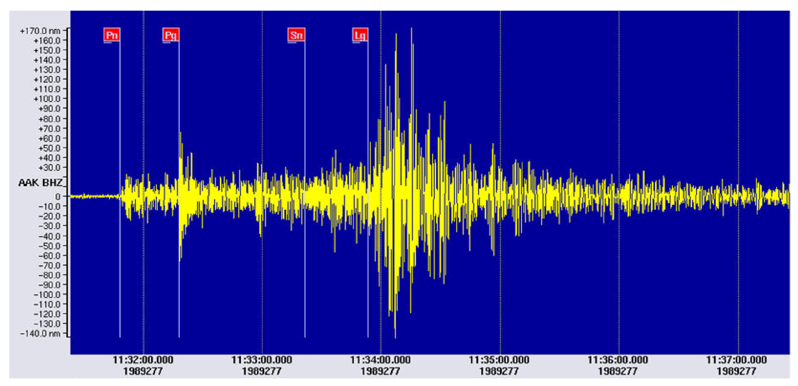

Figure 13. Seismic record of the UNE of October 4, 1989, t0 = 11:30:00.16, φ =49.7498°, λ =78.0117°, mb = 4.7. Z-component.

The seismogram is characterized by a clear arrival of Pn-phase, with domination of Lg amplitude, the amplitude ratio of Lg/Pg > 1. Figure 14 shows the distribution of the Sn/ Pn, Lg/Pn, Sn/Pg, Lg/Pg spectral ratios. The separation of their parameters is not observed for any of the frequencies, owing to the fact that only the digitized records of UNEs were used for the analysis, which allow to do the measurements for frequencies up to 1.25 Hz, in some cases up to 2.5 Hz. At the same time, analysis, conducted by Kazakhstan authors [3], indicated that for STS separation of parameters of discrimination of the North Tien Shan stations at a frequency of 5 Hz is observed.

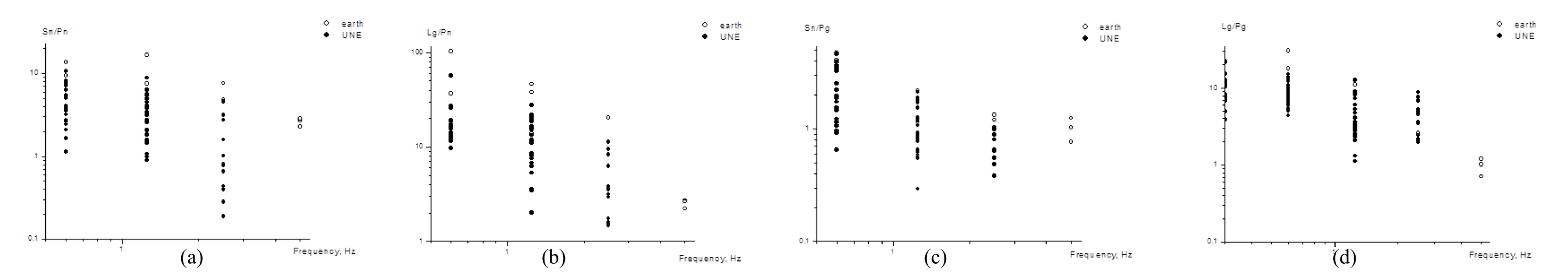

Figure 14. Distribution of maximum amplitudes spectral ratios for the STS area: (a) Sn/Pn; (b) Lg/Pn; (c) Sn/Pg; (d) Lg/Pg.

For the Pakistan Test Site, Chagay, the area bounded by the coordinates of 26.5°-29.5° of northern latitude and 63.5°-66.5° of eastern longitude was considered. 7 records of earthquakes and UNE with epicentral distances from 1632 to 1777 km and mb magnitudes from 4.5 to 7.2 were processed, namely, 1 UNE and 6 earthquakes. Figure 15 shows the seismic record of the UNE of May 28, 1998, t0 =10:16:15.2, φ =28.7919°, λ =64.9475°, mb=4.8. The seismogram is characterized by a clear arrival of P-wave with domination of P-wave amplitude, the S/P amplitude ratio is less 1. Figure 16 shows the distribution of the S/P spectral ratio. A clear separation of their parameters is observed for a filter with a central frequency of 2.5 Hz.

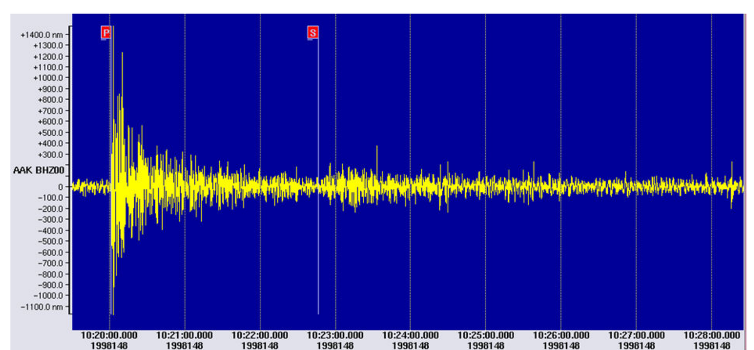

Figure 15. Seismic record of the UNE of May 28, 1998, t0 =10:16:15.2, φ =28.7919°, λ =64.9475°, mb=4.8. Z-component.

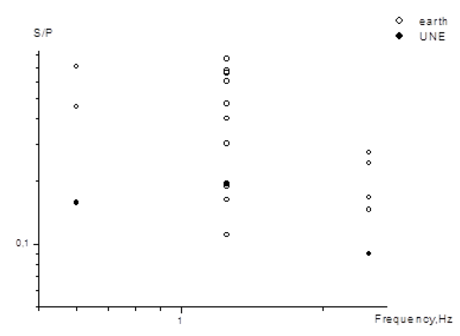

Figure 16. Distribution of spectral ratio of S/P maximum amplitudes of regional seismic phases for the area of the Chagay Test Site.

As for the North Korean Test Site, Punggye-ri, the AAK seismic station is located at a distance of 4443-4446 km. Figure 17 demonstrates the waveforms of nuclear tests of October 9, 2006; May 25, 2009; February 12, 2013; January 6, 2016; September 9, 2016.

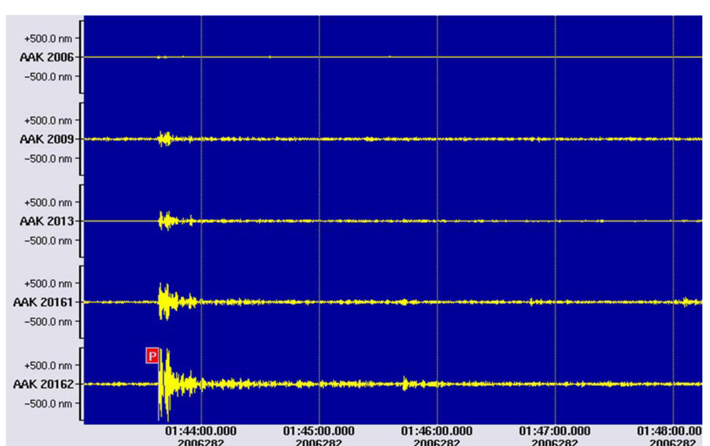

Figure 17. Comparative analysis of North Korean nuclear tests according to the data of AAK station (records from the top to bottom: October 9, 2006; May 25, 2009; February 12, 2013; January 6, 2016; September 9, 2016). Z-component. The filter is 1.25 Hz.

According to the data of the «Ala-Archa» seismic station (AAK) located in the Northern Tien Shan, the structure of short-period seismic fields of underground nuclear explosions produced at the STS, Lop Nor, Pokharan and Chagay Test Sites, as well as earthquakes, occurred in the close area to these test sites were studied. Records of approximately 80 events with magnitudes of 3.7-7.2 and epicentral distances of 837-1846 km from the station have been considered. The ratios of the amplitudes of different phases of P- and S-waves for narrow-band filters with central frequencies of 0.3, 0.6, 1.25, 2.5, and 5 Hz were analyzed. Parameters that ensure the most effective discrimination of explosions and earthquakes were determined for each test site. Namely, for the Lop Nor Test Site the Sn/Pn, Sn/Pg, Lg/Pn, Lg/Pg ratios for frequencies 2.5, 5 Hz were determined, for the Pokharan the S/P parameter for a filter with a central frequency of 1.25, 2.5 Hz was found, as for Chagay Test Site, the filter with a central frequency of 2.5 Hz was used.

Except of above-mentioned, it is necessary to notice that data from all seismic stations of Kyrgyzstan are transmitted to the different international seismological centers and are processed jointly with data from other stations in the world. This one will allow ensure more high level of reliability of the Comprehensive Nuclear Test Ban Treaty (CTBT) implementation.