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Processing of Seismic Signals from a Seismometer Network

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SUMMARY

A description is given of the Seismometer Network Analysis Computer (SNAC) which processes short period data from a network of seismometers (UKNET). The nine stations of the network are distributed throughout the UK and their outputs are transmitted to a control laboratory (Blacknest) where SNAC monitors the data for seismic signals. The computer gives an estimate of the source location of the detected signals and stores the waveforms. The detection logic is designed to maintain high sensitivity without excessive "false alarms". It is demonstrated that the system is able to detect seismic signals at an amplitude level consistent with a network of single stations and, within the limitations of signal onset time measurements made by machine, can locate the source of the seismic disturbance.

1. INTRODUCTION

MOD(PE), Blacknest has installed a network of seismometers in the UK to provide data to evaluate methods of detecting and identifying seismic signals (UKNET). The instruments employed are of the electronic feedback type which in their present configuration provide a "velocity broad band" (VBB) output and a narrow band long period (NBLP) output. The VBB output which is flat to ground velocity from 20 s period to 4 Hz is easily converted to a conventional short period response. Thus, the UKNET is a source of data for research into short period, broad band, and long period networks. This report is concerned with performance of an on-line processor which uses the short period data from the network to detect seismic signals from sources at teleseismic distances and to estimate the epicentres of these sources.

New (1) and Key at al. (2) describe detection processors developed by MOD(PE), Blacknest that work on the data from seismic arrays with apertures (maximum linear dimensions) of 10 to 25 km. Such arrays are small enough for the outputs of the seismometers to be summed with suitable time delays to form overlapping beams to cover the whole of the teleseismic region. This improves the signal-to-noise ratio in proportion to the square root of the number of array elements which, in turn, improves the detection capability. The size of UKNET is such that it would require an impossibly large number of beams to cover the teleseismic region, so no beam-forming is done and the detection capability of the network is therefore no better than that of a single station. However, by cross-correlating the waveforms of detected signals, more accurate relative arrival times can be measured, resulting in better accuracy of source location than is given by the "fixed beam" processors referred to earlier.

The program which performs the processing of the network data is named SNAC (Seismometer Network Analysis Computer) and, in addition to the detection tasks, it collects noise samples at regular intervals for each of the stations and determines the root-mean-square (RMS) amplitudes. It is the SNAC program that is described here. The detection performance is compared to that of the processor in operation at the Eskdalemuir (EKA) array in Scotland; this array has an aperture of 10 km.

2. THE UKNET

Figure 1 shows the distribution of the 9 UKNET stations which are presently used by SNAC. The seismometers at six stations are installed in Royal Observer Corps posts; those at WOL and EKA are MOD sites, and CWF is run from Leicester University. Each station is connected to Blacknest via a leased telephone line which carries the two frequency modulated carriers which transmit the output signals (VBB and NBLP). In the recording laboratory at Blacknest the VBB signals are digitised at 20 samples/s by a Frequency Modulation to Digital Converter, FMDC (3), and interfaced to the SNAC computer.

The computer is a Digital Equipment Corporation PDP11/34 with 32K words of semi-conductor memory. The software system device is an RX02 which contains dual double density floppy-disc drives, and the console device is a 30 character per second Decwriter terminal. SNAC has been operational since January 1981 although it is only recently that all the 9 stations for which SNAC was designed have become operational.

3. OUTLINE OF SNAC

The aim of the SNAC system is to detect P-wave signals from seismic events at teleseismic distances (ie, greater than 30^{o}). This means that it has to deal with waveforms with a dominant frequency in the 0.5 to 2 Hz band and an apparent surface speed (hereinafter referred to as speed) of 10 km/s or more. The maximum dimension (or aperture) of UKNET is about 500 km, so the detection "window" required for a signal to reach each station should be at least 50 s. To obtain the best possible signal-to-noise ratio, the dominant microseismic noise which occurs at about 6 s period, and which is well reproduced by the broad band response, must be filtered-out. The detection process, therefore, operates on signals which are filtered using a simple convolution type filter (similar to that described by Key et al. (2)) which gives at attenuation of greater than 60 db at 6 s period and greater than 80 db at 10 s. The filter response is given in figure 2.

Detections are indicated by a comparison of the short-term average, STA (a $1\frac{1}{2}$ s square window integration of the amplitude of the filtered signal) with the long-term average, LTA (a 30 s exponential amplitude integration) for each station. When the STA exceeds the LTA by the threshold level for that station, a "trigger" is indicated. Waveform data from all stations from about 10 s before the trigger time are then stored, after 50 s, the number of stations that have triggered is determined. If an insufficient number have detected a signal within the time "window", the data are discarded and a "false trigger" logged, otherwise, data for a full minute are stored and the process of determining the location of the event is initiated.

For optimum location, the relative onset times should be measured as accurately as possible. Thus, a process of cross-correlation of the waveforms immediately following each trigger time is performed. From these times, a rough velocity (azimuth and speed) for the signal is calculated using a simple triangulation process for three of the stations. If the signal has a speed in the appropriate range, it is used with the calculated back-bearing (azimuth-180^{o}) to determine a rough epicentre and origin time. Using these data, together with the relative arrival times of all the contributing stations, an iterative process of epicentre location is carried out (4). The results are printed-out and, together with 60 s of waveform data, are entered in a floppy disc file which is later archived on ½ in. magnetic tape.

4. INPUT DATA QUALITY

If a false trigger occurs at one station, followed by a genuine signal within the 50 s time window, the processing would be confused and later arrivals of the genuine signal may not be considered. This could result in the genuine signals being discarded due either to the computed speed being too slow or to there being an insufficient number of stations triggering. It is important therefore that false triggers be kept to a minimum, but without excessively desensitising the system. False triggers can occur from a number of causes:-

(a) Cultural noise - machinery and/or human or animal activity near the station.

(b) Noisy telephone lines - spikes introduced into the FM signal or intermittent interruptions of the signal.

(c) Intermittent electronic faults in the recording laboratory equipment.

(d) Excessive detection sensitivity, ie, too high a sensitivity factor.

These problems are dealt with in one of three ways:-

(i) Temporary removal of a station from the process.

(ii) Automatic adjustment of the sensitivity factor.

(iii) Placing of a station into a reduced priority category (called category B).

Before discussing the three solutions the concept of minimum contributing stations (MCS) will be described. Clearly, for a location to be determined, the minimum number is three. However, with a network of 9 stations and no gross differences in performance this value is unrealistically small and could result in false detections caused by a random concurrence of triggers. One of the advantages of more than 3 stations in a network is the improvement in the confidence with which one can specify a genuine seismic signal. The MCS definition chosen for the programme is $(N + 1)/2$ or 3, whichever is the greater, where N is the number of stations currently on-line. This number of stations must have triggered for the signals to be treated as a detection.

4.1 Channel status

The format of the digital data from the FMDC is that each sample is a 16 bit word with the least significant bit used as a status "flag". If the bit is clear, the data are valid, but if the input FM signal is too small or is interrupted or the deviation is too large, the bit is set. The status bit for each channel and every sample is monitored and if 5 successive samples on any channel are flagged as invalid, then that channel is taken off-line and the data ignored. This also reduces the MCS. On-line status is re-examined and if possible restored after 20 min, both changes being indicated on the print-out. In this way the effect of noisy lines and/or faulty electronics is minimised and brought to the attention of staff. If multiple failures reduce the number of on-line stations to less than 3, a warning message is printed (Insufficient Usable Channels) and the re-check of channel status is done after only 5 s instead of 20 min.

4.2 Automatic adjustment of sensitivity factor

Every $1\frac{1}{2}$ s, a proportion of the STA value is added to the exponentially decaying LTA to form the new value. The divisor used for this proportion combined with the inherent gain of the integration process results in the LTA having a value greater than the STA during normal conditions of seismic noise. Varying the value of the divisor varies the normal separation between the two and hence the sensitivity of the station to transient changes in STA, and this is used in SNAC to optimise the sensitivity of each station.

Each station has its own STA divisor (ie, sensitivity factor or SF) which initially is set at 30. A count is maintained of the number of false triggers per channel which occur in each one hour period. Each station is "allowed" one false trigger per hour. If this is exceeded, the surplus is subtracted from its SF, whereas if none occur, SF is incremented (but the SF value is not allowed to go below 15). Whereas this process stabilises the sensitivities of the stations, it still "allows" up to nine false triggers per hour (with all the implications referred to earlier) and can result in the sensitivity at stations with high cultural noise being reduced to too low a level.

4.3 Category B status

This reduced priority status was introduced to combat the two disadvantages described above. In addition to the SF for each station there is a further SF which applies to all "Category B" stations, SF(B). When a station has a large number of false triggers and its SF is adjusted, the new lower value is compared with the SF(B) value. If it is found that it is lower than SF(B), the station is given "Category B" status and its SF the SF(B) value. It thus retains a higher sensitivity than it would otherwise be given. This status is indicated by making its SF negative although the sign is ignored when forming the LTA. The number of stations that can be given B status is equal to N - MCS (ie, the number of stations with full status must be not less than MCS). The value of SF(B) is adjusted as follows: if the number of B stations is less than N - MCS, SF(B) is incremented - if the full number of B stations has been allocated, but a full status station is given a new SF lower than SF(B), then SF(B) is given that new lower value, and all B stations follow suit. Thus, SF(B) can never be greater than any full status SF. If a B station has one or less false triggers in an hour, it is restored to full status. If one of the full status stations should go off-line so that there are less than MCS, B stations are restored to full status one by one until there are sufficient.

Operationally, the effect of B status is as follows. If a B station indicates a trigger, the time is logged, as normal, but it does not initiate a sequence of data storage. If, after 10 s, no other station has triggered, the time is discarded and the trigger ignored. In this way, stations subject to local noise can be maintained at a high sensitivity without impairing the general performance.

Once a detection is indicated by having MCS or more stations triggering, the interrupts which accept and process incoming data are temporarily disabled (usually for no more than 10 s). The entire 60 s of stored data are then read back into memory from the floppy disc.

5. CROSS-CORRELATION

The process of cross-correlation of the detected waveforms is used to refine the trigger times prior to the epicentre location determination. During the transfer of the 1 min length of data to the floppy disc, its frequency response is changed from velocity broad band to "conventional" short period. This is done using a 2 pole recursive filter with a response equivalent to a simple 1 Hz seismometer with 0.6 damping. The filtering considerably improves the signal-to-noise ratio of P wave signals thus enabling most signals to be cross-correlated without further filtering.

The normal cross-correlation process has been modified so as to reduce the amount of coding required, and the computing time taken. Instead of the cross-product of each sample, a pseudo log is used, which takes the highest set bit number of each sample (ie, in the range 0 to 15) and adds or subtracts it from a counter, according to the sign coincidence of the two waveforms. A running total of the maximum possible count is also kept and this is used to normalise the result to a percentage.

Stations are allocated to FMDC channels (1 to 9) and this list determines the order in which they are multiplexed (see section 6). The station highest on the list (ie, lowest channel number) to have detected a signal is taken as the standard against which all the others are compared. There are three stages that can be used, the aim being to reach a 50% or more correlation. In the first stage, 7 s of record from each detecting station are compared in turn against the standard station by time shifting the data over a range of ± 2.5 s. The time shift giving the maximum value of correlation is used to correct the trigger time for the station concerned, unless the maximum value is less than 50%, in which case the next stage is entered. In the second stage, the length is reduced to 3 s and the time shift to ± 1 s. If necessary the third stage can be used; this stage is similar to the second, except that the waveform data are band-pass filtered using the same filter as used in the detection process. Failure to meet the 50% target after the third stage causes the data from that channel to be ignored by later processes and this is indicated in the subsequent print-out by having the trigger time followed by a "?".

After all the channels have been cross-correlated, the number which have been successful is again examined and if less than 3, all the data are discarded. Otherwise, the new refined trigger times are used to time shift each valid channel to form a sum-all signal for the network. Each channel is given equal weighting and the sum is normalised to a single channel. These data are included in the multiplexed data as channel 10.

6. EPICENTRE DETERMINATION

The first stage is to get a rough estimate of the epicentre using data from stations on the first 3 channels to detect. The order in which stations are allocated to the list of channel numbers is important because of this initial estimate and because of the cross-correlation process. The present allocation is the result of experience of signal fidelity and an effort to ensure that the first three listed stations to detect will be well separated geographically. The geographical co-ordinates of all the stations are stored in the program and on entry a three-dimensional table is calculated which contains the back bearing and distance of each station to every other subsequent one. This table is accessed and from a simple triangulation process the back bearing from the national centre of the network to the signal source and the speed of the signal are calculated.

If the speed is less than 9 km/s, the data are discarded. If the speed is 25 km/s or more, the event is designated as being from the core shadow zone and this information, together with the station trigger times, is printed out and the waveform stored back on to the floppy disc as a permanent file. Using data from the standard Jeffrys and Bullen seismological travel times (for surface focus) the distance corresponding to the signal speed is found. As the speed is almost constant with distance beyond 90°, distance estimation is poor for such signals, so they are also classed as core shadow. All other signals have the epicentre estimates re-calculated using the refined onset time data from all the contributing stations and employing an iterative process to reduce errors to an acceptable level.

Using the distance found previously, rough epicentre co-ordinates are calculated and from the travel time data, a relative origin time. The travel time to each station from the epicentre is determined and compared with the observed arrival time. The epicentre co-ordinates and origin time are then adjusted in such a way as to minimise the sum of the squared errors (ie, where the errors are the differences between the observed signal onset times and the predicted times). Once either the epicentre position or the sum of the squared errors changes by less than a specified amount, the iterative process is assumed to have converged. The errors (station residuals) are examined and if any are greater than 1.0 s, the station with the largest residual is removed. The procedure then followed is that described below for the "no convergence" condition. Otherwise, the results are printed out after reference has been made to standard tables of seismic region to obtain the name of the area of the epicentre. All these data are stored in the first block of the waveform data file.

If convergence does not occur after 20 iterations, the station residuals are examined. The station with the largest residual is discarded as above (this will be indicated in the subsequent print-out by having a "*" after the trigger time) and the process then loops back to re-assemble the sum-all signal, re-compute the rough epicentre and re-enter the final iterative process. In this way the number of stations may be reduced to 3 in which case, if there is still no convergence, the rough epicentre co-ordinates are given to the nearest degree (not to the nearest tenth as normally) and the trigger times given to the nearest second.

Finally, the counters containing the number of false triggers since the last detection, together with various data buffers, are cleared, the data interrupts are reactivated and a "settling-down" delay of 30 s allowed before the detection process restarts. A typical event printout is shown in figure 3.

7. NOISE MEASUREMENTS

In addition to its function as a seismic signal detector, SNAC also collects regular noise measurements for each station. A file is created for this purpose whenever a new empty disc replaces one containing data. The file is named NOISE.UKN and is 10 blocks in length. Noise samples are 1 min in length and are taken every six hours at 0000, 0600, 1200 and 1800 hours. The incoming data are converted to short period form and the RMS values calculated. These are converted to ground movement by using the system sensitivity factor for a frequency of 1 Hz. For each sample, 21 words of data are stored. They are:-

(a) Two words - data/time data.

(b) Nine words - noise measurements for each station.

(c) One word - number of on-line channels.

(d) Nine words - sensitivity factor for each station.

Results show that for all stations the noise level is higher at 1200 hours than at other times through the day. They range from a minimum of 3 mμm at CWF to a maximum of 57 mμm at BHM.

8. SYSTEM OPERATION

The operating system uses an RT11 single job monitor which, together with some system utility programmes and data files, is resident on a double density floppy disc in unit 0 of the dual drive RX02. Processed output data are stored on a single density floppy disc in unit 1. The storage capacity of a single density disc is 480 blocks each of 512 bytes. This is sufficient for the noise file (10 blocks) and up to 9 event files (50 blocks each). Normally when 4 or 5 detections have been recorded, the data disc is replaced with an empty one (the exchange being initiated by a terminal keyboard command). The data are then replayed on a mingograph ink recorder and transferred to magnetic tape using the ANDAC facilities (Array Network Data Analysis Computer - a PDP11/34 based system).

Although the data disc can contain 9 event files, in practice no more than 8 are ever used. If there are more than 8 detections, empty space on the disc in unit 0 is used to store a further 4 files. After this, no more files are created but the storage space for the 9th file on unit 1 is used temporarily to store waveform data for any subsequent detections so that a full set of details of the event can be determined and printed-out. This situation is unlikely to occur, except for the rare occurrence of a very large earthquake swarm or aftershock sequence.

9. PERFORMANCE

9.1 Detection

The files containing waveform data for detected events, together with noise data files, are stored on 600 ft digital magnetic tapes at 800 bpi. As each tape is filled the data are analysed to provide statistics of station and network performance. These show that during 1982 SNAC detected 253 events. This compares with 978 detections by the EKA station processor which operates on the output of a 20 element array. This ratio of just under 4 to 1 is slightly better than the expected result where the signal-to-noise ratio improvement from summing an array is equal to the square root of the number of elements.

A plot of the cumulative number of detections as a function of amplitude is given in figure 4. This indicates that SNAC should detect 90% of all events with amplitudes of 45 m μm or more, equivalent to a magnitude of 5.5 m_b for teleseisms.

9.2 Location

About half the detected signals had a speed which classified their source as "core shadow". For the period 1 January 1981 to 30 September 1982, 202 core shadow events were detected by SNAC. Of these 158 could be associated with epicentres reported by either NORSAR or NEIS. The principal areas from which PKP detections are made by SNAC are:-

Loyalty Islands
Fiji Islands
South of Fiji Islands
Tonga Islands
Vanuatu Islands
Banda Sea
New Britain
Kermadec Islands
Solomon Islands

The locations given by SNAC using the iterative process were compared with those given by NEIS. The back bearing and speed for each were determined and the errors in each were calculated. Table 1 lists these for all the signals in the 6 months July to December 1982. The mean back bearing error is $\pm 2.17^{\circ}$ with a standard deviation of 1.98°, whereas for speed the mean error is ± 4.25% with a standard deviation of 4.04%.

It is possible that due to the siting of stations and/or the local geology, teleseismic signals may always arrive later or earlier than the standard travel time-tables would suggest. These "station corrections" may be azimuth dependent but this was not investigated.

Signals which have been detected since the beginning of July 1982 and for which at least five stations have given valid arrival times have been used to estimate corrections. Taking the hypocentre details given by NEIS, the relative station residuals have been calculated. These, together with the back-bearings, are given in table 2. (Data for BHM are not included because of the small number of observations available.) The mean values, together with standard deviations, are given at the foot of each column. These range from + 0.18 s for SBD to - 0.13 s for SHT. It is thought that these corrections are probably too small to make any significant change in epicentre estimates for a network of the size of UKNET.

10. CONCLUSIONS

Compared with the results of the EKA processor, which operates on the sum of 20 seismometers, the SNAC system, which operates on single seismometers only, has a detection threshold well up to expectation. The location performance is somewhat disappointing. This is due in the main to the emergent nature of some of the waveforms and/or their lack of coherence over the distances involved. This results in errors in the picking of the relative arrival times and hence in the location calculation. However, with this limitation in mind it is quite feasible for the replayed data to be examined by an experienced analyst to make refined measurements and re-calculate the epicentre, using the off-line facilities (ANDAC) at Blacknest. The SNAC epicentre always provides a reliable first estimate of the location.

11. ACKNOWLEDGMENTS

The authors would like to thank Mr B D Hopkins, who designed and supplied an additional interface between the FMDC and the PDP11, and also Mr F H Grover, who was responsible for the installation of the UKNET and who has also made many helpful suggestions for inclusions in SNAC.

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TABLE 1

Summary of Details of Events Detected by SNAC
July to December 1982

	SNAC			NEIS				
Date	Epicentre Coordinates	Back Bearing (°)	Speed (km s^{-1})	Epicentre Coordinates	Back Bearing (°)	Speed (km s^{-1})	Back Bearing Error °	Speed % Error
1 Jul	53.1N 175.2E	1	18.5	51.4N 180.0E	2	19.0	1	2.7
1	34.4N 75.6E	77	15.4	36.6N 70.7E	79	14.6	2	5.2
2	36.5N 71.0E	78	14.7	36.7N 71.7E	78	14.8	0	0.7
3	43.0N 148.6E	21	20.3	44.7N 151.0E	18	20.1	3	1.0
5	31.3N 138.4E	32	23.0	31.0N 130.5E	38	22.2	6	4.0
11	27.6N 57.4E	97	14.6	27.8N 56.2E	98	14.5	1	0.7
14	46.4N 136.7E	28	18.7	45.9N 143.4E	23	19.2	5	2.7
20	54.9N 162.4E	9	18.1	54.5N 161.5E	9	18.1	0	0
23	33.9N 30.4E	119	12.6	39.0N 25.3E	119	11.6	0	7.9
23	34.7N 140.5E	29	22.1	36.2N 141.8E	28	21.8	1	1.3
27	46.2N 122.5W	319	17.4	43.9N 128.3N	321	18.2	2	4.4
31	54.8N 168.4W	351	18.1	51.7N 176.2E	355	18.9	4	4.2
3 Aug	47.5N 94.0E	54	15.4	48.9N 89.7E	55	15.0	1	3.9
4	40.0N 20.7E	124	11.1	39.7N 20.2E	126	11.1	2	0
5	40.0N 115.5W	310	17.9	37.1N 116.0W	309	18.4	1	2.7
7	34.0N 76.9E	76	15.7	36.4N 71.5E	78	14.8	2	5.7
8	42.3N 151.7E	19	20.7	51.1N 156.4E	13	18.7	6	9.7
9	42.6N 30.0W	245	11.0	43.6N 28.9W	245	10.3	0	6.3
17	36.6N 21.2E	128	11.6	33.7N 27.0E	123	12.4	5	6.4
23	36.7N 143.1E	27	21.8	36.3N 141.5E	28	21.8	1	0
24	54.7N 168.1W	351	18.1	53.7N 165.4W	349	18.1	2	0
31	51.9N 70.9E	63	13.5	49.9N 78.8E	60	14.0	3	3.5
3 Sep	42.3N 150.9E	19	20.7	43.9N 148.5E	20	20.1	1	2.9
3	42.5N 148.0E	21	20.4	43.8N 148.5E	21	20.2	0	1.0
3	44.2N 148.9E	20	20.1	43.8N 148.4E	21	20.1	1	0
4	69.2N 95.5E	31	13.5	69.2N 81.7E	35	13.2	4	2.2
5	7.8N 92.0W	274	21.5	14.1N 91.8W	277	20.1	3	1.9
8	33.2N 142.1E	29	22.7	27.1N 140.1E	32	24.2	3	6.1
10	41.2N 21.0E	122	10.9	38.2N 22.8E	124	11.5	2	5.2
12	42.0N 167.7W	348	21.3	52.7N 166.9W	350	18.3	2	14.1
12	51.3N 167.7W	350	18.8	52.8N 167.0W	350	18.3	0	2.7
21	48.8N 78.6E	62	14.1	49.9N 78.2E	61	14.0	1	0.7
25	68.5N 86.7E	35	13.4	64.3N 91.9E	38	13.7	3	2.2
29	35.3N 74.9E	77	15.2	37.3N 72.9E	76	14.9	1	2.0
29	15.1N 88.0W	275	19.2	14.5N 89.0W	275	19.5	0	1.5
16 Oct	49.3N 41.4E	84	12.2	46.7N 48.2E	83	12.7	1	3.9
16	49.4N 39.9E	85	12.0	46.7N 48.2E	83	12.7	2	5.5
16	49.1N 43.3E	83	12.3	46.7N 48.2E	83	12.7	0	3.1
21	31.6N 46.0E	104	13.5	28.5N 52.0E	101	14.0	3	3.6
25	21.7N 102.9W	290	20.1	18.4N 106.0W	291	21.3	1	5.6
25	35.9N 117.9W	310	19.0	36.3N 120.5W	312	19.1	2	0.5
4 Nov	39.3N 146.2E	23	21.3	44.1N 143.0E	24	19.8	1	7.0
15	32.6N 4.6E	163	11.3	35.5N 1.3E	169	10.2	6	9.7
16	41.1N 19.8E	124	10.7	41.0N 19.5E	124	10.6	0	0.9
17	34.3N 24.4E	126	12.3	40.9N 19.6E	124	10.7	2	13.0
20	34.0N 76.0E	77	15.5	34.6N 70.6E	80	15.0	3	3.2
23	17.9N 62.5W	255	15.9	17.6N 62.1W	254	15.9	1	0
27	46.6N 147.6W	335	19.1	50.1N 147.8W	337	18.2	2	4.7
2 Dec	52.9N 160.9W	346	18.2	51.9N 170.3W	352	18.7	6	2.7
5	48.1N 82.8E	60	14.5	49.9N 78.8E	60	14.0	0	3.5
13	3.7N 45.9E	124	17.2	14.8N 44.3E	119	15.1	5	12.2
17	39.3N 125.5E	39	19.5	24.6N 122.6E	48	23.0	9	15.2
22	45.0N 31.8W	252	10.7	46.1N 27.6W	249	8.9	3	16.8
24	53.9N 171.4E	3	18.2	52.5N 173.3E	2	18.7	1	2.6
					Mean		2.17	4.25
						± SD	1.98	4.04

TABLE 2

Arrival Time Errors in Seconds for Each Station Derived from NEIS Epicentre Data

Date	B-B*	LLW	SBD	WOL	MMY	CWF	BHM	EKA	LAM	SHT
1 Jul	2	-0.13		-0.23		-0.37			0.30	0.43
1	79	-0.43		0.40	-0.96	1.20		0.33	-0.81	0.27
2	78	0.05		0.09	0.11	-0.40		0.18	0.03	-0.06
11	98	-0.15		0.23	-0.25	-0.43		-0.44	1.05	-0.01
14	23	0.24		-0.22	1.21	-1.17		-0.04	0.17	-0.19
20	9	-0.14		-0.46	-0.30	0.84		-0.19	-0.36	0.63
23	119	0.15		-0.33	0.22	-0.20		0.18	-0.02	
27	321	-0.16	-0.01		-0.07	0.40				-0.15
31	355	0.15	-0.08		-0.13			0.15	0.00	-0.10
5 Aug	309	-0.22	-0.02	0.42	0.06	0.31		0.52	0.16	-0.18
7	78	-0.30		-0.17	+0.21	1.17		-0.11	-0.78	0.41
23	28	0.05		0.60	0.05	-0.36		-0.10	-0.23	
24	349	-0.17	0.82	-0.08	-0.29	-0.15		-0.14		0.31
31	60	0.31		-0.05	-0.80	-0.14		0.20	0.88	-0.40
3 Sep	20	0.30		0.16	0.01	-0.16			0.12	-0.42
3	21	0.11		-0.02	-0.18	0.57			0.14	-0.61
3	21	-0.35		0.20	0.17	0.10			0.37	-0.48
4	35	-0.08		0.74	-0.09	0.24				-0.81
5	277	0.04		-0.66	0.61	0.18				-0.18
21	61	0.51	-0.06	-0.27	0.32			-0.14	0.50	-0.36
25	38	0.40			0.35	-0.18		-0.83	0.26	
29	76	0.09		0.13	0.07			0.08	0.24	-0.63
29	275	-0.16	0.03	0.09	0.12			0.07		-0.15
16 Oct	83	0.39		0.15	-0.36	-0.32		-0.07	0.22	
16	83	0.44		-0.40	-0.32	-0.17		0.08	0.37	
16	83	0.41		-0.64	-0.83	0.15		0.72	0.20	
21	101	-0.28	0.37		0.31	-0.58			0.18	
25	291	-0.17	-0.10		0.41				0.26	-0.39
4 Nov	24	0.18			0.05	-0.14		0.73	0.16	-0.98
16	124	-0.33			-1.18	0.72		0.10	0.62	0.07
20	80	-0.91		1.54	-0.17	-0.35		-0.15	-0.85	0.88
23	254	0.06	0.04	0.13	-0.20	-0.09		-0.21	0.21	
27	337	-0.06	-0.75	-0.67	0.18	-0.22		0.37	1.16	
2 Dec	352	-0.17	-0.68	0.65	0.33	0.51		-0.37		-0.45
5	60	-0.50		0.05		0.05	0.45	0.19	0.19	-0.41
13	119	0.14	0.11	0.52	-0.49	-0.87	0.56	-0.39	0.19	
17	48		1.85	0.67	-2.81		0.92		-0.32	0.76
24	19	0.13	0.96	-0.91	0.47	-1.07		0.88		-0.14
24	2	-0.18	0.51	-0.22	-0.39	0.16	-0.06	-0.20		0.37
24 Jan	77	-0.17	0.04	0.01	0.05		0.27	-0.22	0.18	-0.16
24	281	-0.42	0.06	0.31	-0.34				0.39	0.00
24	281	-0.31		0.15	0.28			0.02	-0.04	-1.11
	Mean	-0.04	0.18	0.05	-0.11	-0.01	0.43	0.04	0.15	-0.13
	SD	0.23	0.61	0.48	0.62	0.55	0.36	0.36	0.44	0.47

* Back Bearing in degrees

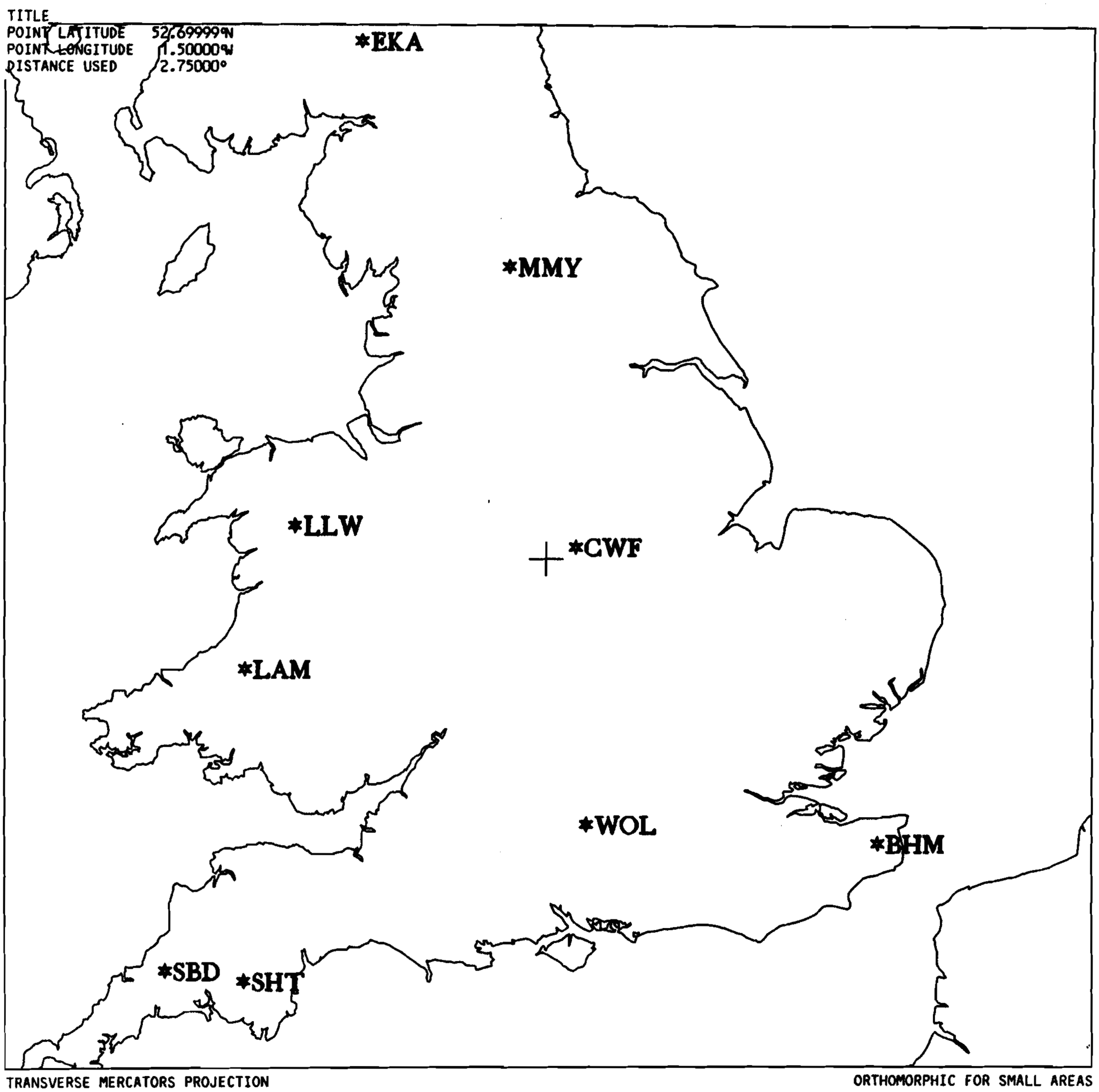

FIGURE 1. DISTRIBUTION OF THE 9 UKNET STATIONS PRESENTLY USED BY SNAC

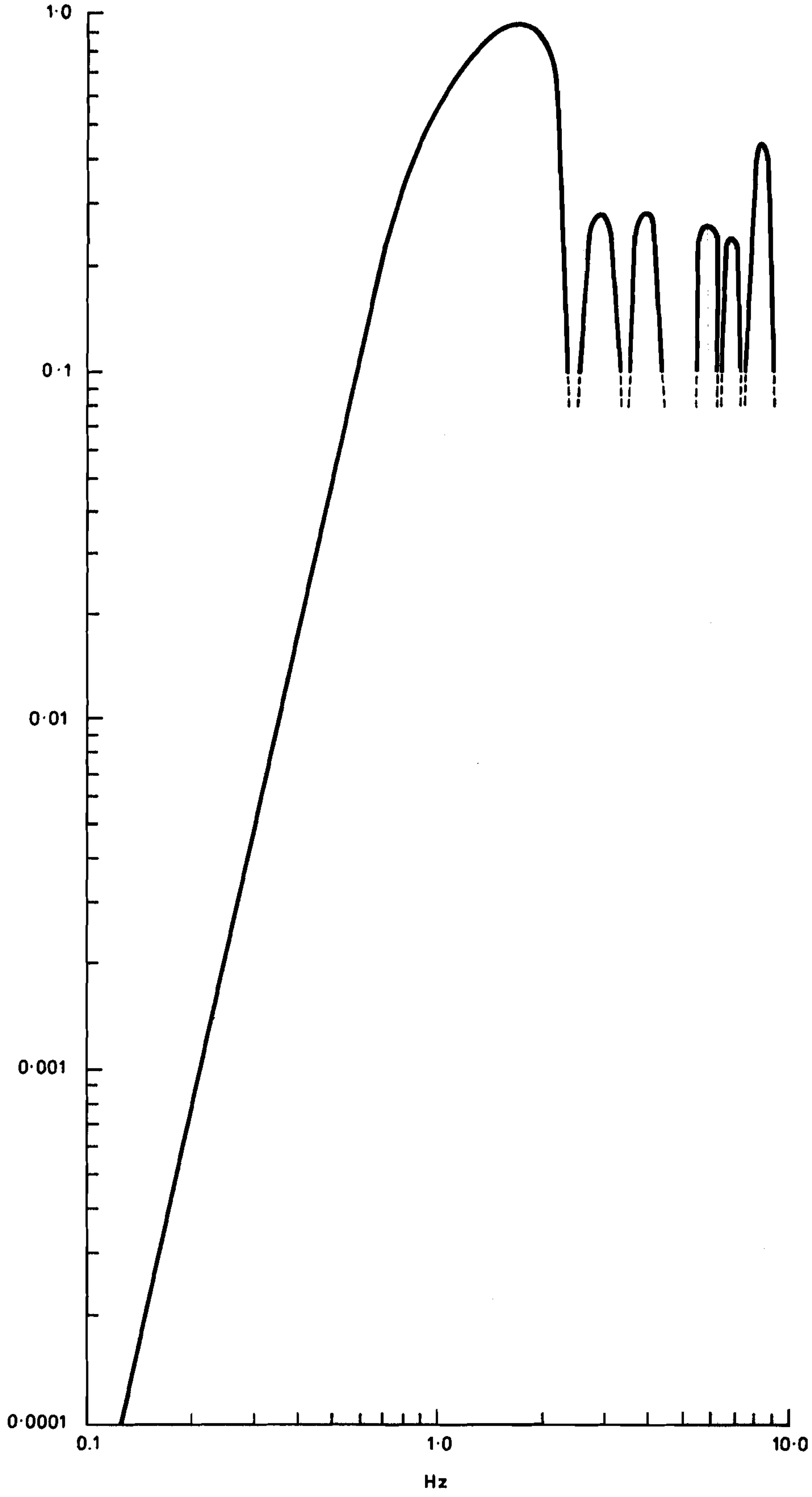

FIGURE 2 Frequency Response of the Filter Used in the Detection Process

```
099   8-MAR-83  17:16:30 11.9N  63.3W CARIBBEAN SEA                     252 17.08 U
LLW 17:16:53.2  0.01 Travel time 10 : 26.9
SBD 17:16:44.7  0.12
WOL 17:16:59.7 -0.23
MMY 17:17:02.5  0.01
CWF 17:17:01.8 -0.19
BHM 17:17:09.5  0.23
EKA 17:17:00.1  0.01
LAM 17:16:50.3  0.12
SHT 17:16:47.0 -0.09
     peak-to-trough amplitude in digits =  326
     zero-to-peak displacement  100.4 millimicrons at 1.0 seconds period.
  3 iterations
```

FIGURE 3. TYPICAL EVENT DETAILS PRINTED BY SNAC

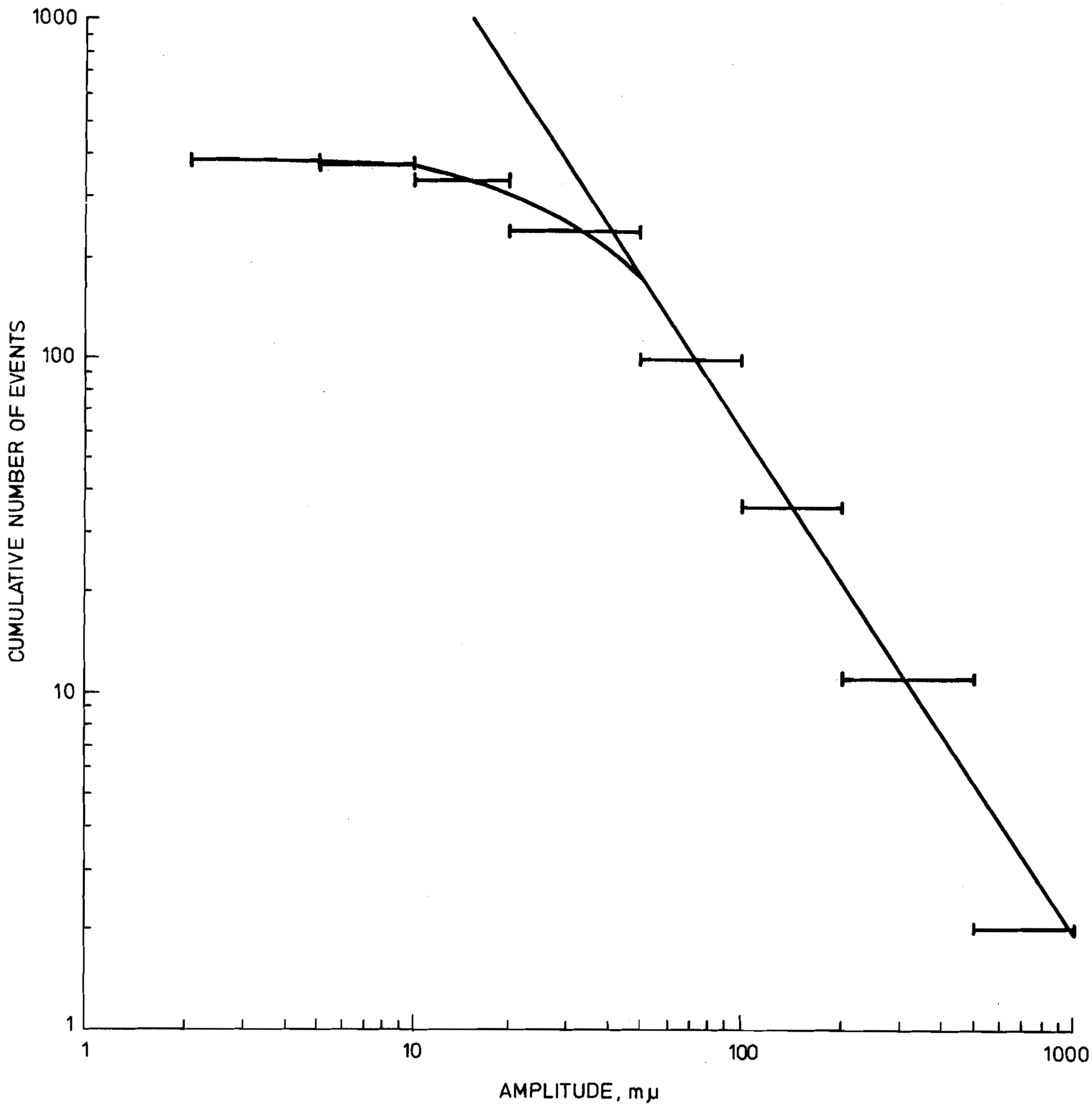

FIGURE 4. CUMULATIVE NUMBER OF DETECTIONS AS A FUNCTION OF SIGNAL AMPLITUDE

DOCUMENT CONTROL SHEET

Overall security classification of sheet ......UNCLASSIFIED.......

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification
-	AWRE Report No. O19/83	-	UNLIMITED

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
-	Atomic Weapons Research Establishment, Aldermaston, Berkshire
5a. Sponsoring Agency's Code (if known)	**6a. Sponsoring Agency (Contract Authority) Name and Location**
-	-

7. Title

Processing of Seismic Signals from a Seismometer Network

7a. Title in Foreign Language (in the case of Translation)

-

7b. Presented at (for Conference Papers). Title, Place and Date of Conference

-

8. Author 1.Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	pp	ref
Key F A	Warburton Penelope J	-	August 1983	18	4

11. Contract Number	12. Period	13. Project	14. Other References
-	-	-	-

15. Distribution Statement

No restriction

16. Descriptors (or Keywords) (TEST)

Seismic detection
Seismic arrays
Seismometers
Seismological stations

Abstract

A description is given of the Seismometer Network Analysis Computer (SNAC) which processes short period data from a network of seismometers (UKNET). The nine stations of the network are distributed throughout the UK and their outputs are transmitted to a control laboratory (Blacknest) where SNAC monitors the data for seismic signals. The computer gives an estimate of the source location of the detected signals and stores the waveforms. The detection logic is designed to maintain high sensitivity without excessive "false alarms". It is demonstrated that the system is able to detect seismic signals at an amplitude level consistent with a network of single stations and, within the limitations of signal onset time measurements made by machine, can locate the source of the seismic disturbance.

Some Metric and SI Unit Conversion Factors

(Based on DEF STAN 00-11/2 "Metric Units for Use by the Ministry of Defence", DS Met 5501 "AWRE Metric Guide" and other British Standards)

Quantity	Unit	Symbol	Conversion
Basic Units			
Length	metre	m	1 m = 3.2808 ft 1 ft = 0.3048 m
Mass	kilogram	kg	1 kg = 2.2046 lb 1 lb = 0.45359237 kg 1 ton = 1016.05 kg
Derived Units			
Force	newton	$N = kg\ m/s^2$	1 N = 0.2248 lbf 1 lbf = 4.44822 N
Work, Energy, Quantity of Heat	joule	J = N m	1 J = 0.737562 ft lbf 1 J = 9.47817×10^{-4} Btu 1 J = 2.38846×10^{-4} kcal 1 ft lbf = 1.35582 J 1 Btu = 1055.06 J 1 kcal = 4186.8 J
Power	watt	W = J/s	1 W = 0.238846 cal/s 1 cal/s = 4.1868 W
Electric Charge	coulomb	C = A s	-
Electric Potential	volt	V = W/A = J/C	-
Electrical Capacitance	farad	F = A s/V = C/V	-
Electric Resistance	ohm	Ω = V/A	-
Conductance	siemen	$S = 1\ \Omega^{-1}$	-
Magnetic Flux	weber	Wb = V s	-
Magnetic Flux Density	tesla	$T = Wb/m^2$	-
Inductance	henry	H = V s/A = Wb/A	-
Complex Derived Units			
Angular Velocity	radian per second	rad/s	1 rad/s = 0.159155 rev/s 1 rev/s = 6.28319 rad/s
Acceleration	metre per square second	m/s^2	1 m/s^2 = 3.28084 ft/s^2 1 ft/s^2 = 0.3048 m/s^2
Angular Acceleration	radian per square second	rad/s^2	-
Pressure	newton per square metre	N/m^2 = Pa	1 N/m^2 = 145.038×10^{-6} lbf/in^2 1 lbf/in^2 = 6.89476×10^3 N/m^2
	bar	bar = 10^5 N/m^2	- 1 in. Hg = 3386.39 N/m^2
Torque	newton metre	N m	1 N m = 0.737562 lbf ft 1 lbf ft = 1.35582 N m
Surface Tension	newton per metre	N/m	1 N/m = 0.0685 lbf/ft 1 lbf/ft = 14.5939 N/m
Dynamic Viscosity	newton second per square metre	N s/m^2	1 N s/m^2 = 0.0208854 lbf s/ft^2 1 lbf s/ft^2 = 47.8803 N s/m^2
Kinematic Viscosity	square metre per second	m^2/s	1 m^2/s = 10.7639 ft^2/s 1 ft^2/s = 0.0929 m^2/s
Thermal Conductivity	watt per metre kelvin	W/m K	-
Odd Units*			
Radioactivity	becquerel	Bq	1 Bq = 2.7027×10^{-11} Ci 1 Ci = 3.700×10^{10} Bq
Absorbed Dose	gray	Gy	1 Gy = 100 rad 1 rad = 0.01 Gy
Dose Equivalent	sievert	Sv	1 Sv = 100 rem 1 rem = 0.01 Sv
Exposure	coulomb per kilogram	C/kg	1 C/kg = 3876 R 1 R = 2.58×10^{-4} C/kg
Rate of Leak (Vacuum Systems)	millibar litre per second	mb l/s	1 mb = 0.750062 torr 1 torr = 1.33322 mb

*These terms are recognised terms within the metric system.

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Electric Resistance	ohm	$\Omega = V/A$	-
Conductance	siemen	$S = 1\ \Omega^{-1}$	-
Magnetic Flux	weber	Wb = V s	-
Magnetic Flux Density	tesla	$T = Wb/m^2$	-
Inductance	henry	H = V s/A = Wb/A	-
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			$1\ lbf/in^2 = 6.89476 \times 10^3\ N/m^2$
	bar	$bar = 10^5\ N/m^2$	-
			$1\ in.\ Hg = 3386.39\ N/m^2$
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