U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

# CATALOG OF EARTHQUAKE HYPOCENTERS AT REDOUBT VOLCANO AND MT. SPURR, ALASKA: OCTOBER 12, 1989 - DECEMBER 31, 1990

by

John A. Power[1], Gail D. March[2], John C. Lahr[1], Arthur D. Jolly[1], Gina R. Cruse[1]

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[1] Alaska Volcano Observatory
U.S. Geological Survey,
Geophysical Institute,
University of Alaska,
Fairbanks, AK 99775

[2] Alaska Volcano Observatory
Alaska Division of Geological &
Geophysical Surveys,
794 University Ave, Suite 200,
Fairbanks, AK 99709

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## INTRODUCTION

The Alaska Volcano Observatory (AVO), a cooperative program of the U.S. Geological Survey, the Geophysical Institute of the University of Alaska, Fairbanks, and the Alaska Division of Geological and Geophysical Surveys, began a program of seismic monitoring at potentially active volcanoes in the Cook Inlet region in 1988. Seismic monitoring of this area was previously accomplished by two independent seismic networks operated by the U.S. Geological Survey (Northern Cook Inlet) and the Geophysical Institute (Southern Cook Inlet). In 1989 the AVO seismic program consisted of three small-aperture networks of six, five, and six stations on Mt. Spurr, Redoubt Volcano, and Augustine Volcano respectively. Thirty-five other stations were operated in the Cook Inlet region as part of the AVO program. During 1990 six additional stations were added to the Redoubt network in response to eruptive activity, and three stations were installed at Iliamna Volcano. The principal objectives of the AVO program have been the seismic surveillance of the Cook Inlet volcanoes and the investigation of seismic processes associated with active volcanism.

The locations of seismograph stations operated by AVO between 1988 and 1990 are shown in Figure 1. Geographic coordinates, elevations, and the installation date of each of the stations are contained in Appendix A. Signals from each of the stations are telemetered to Fairbanks, where recording and analysis take place. Data is recorded digitally in event-detection mode on a PC/AT system and continuously and in event-detection mode on a Masscomp system (Alaska Volcano Observatory Staff, 1990). The two event-detection systems employ different triggering parameters, with the PC/AT system having greater sensitivity for events in close proximity to the volcanoes. Data is also recorded on Helicorders, a Real-time Seismic Amplitude Measurement (RSAM) system (Murray and Endo, 1989; Endo and Murray, 1991), and a Seismic Spectral Amplitude Measurement (SSAM) system (Stephens and others, in press). A description of the various components of the computer systems, their networking, and associated software is given by March and Power (1990).

Following a 23 year period of quiescence, Redoubt Volcano erupted between December 14, 1989 and April 21, 1990. The eruption was accompanied by thousands of earthquakes (Alaska Volcano Observatory Staff, 1990). Throughout the eruption sequence, data from the PC/AT system provided the primary means of determining earthquake hypocenters. This report catalogs the earthquake hypocenters and magnitudes calculated from data collected between October 12, 1989 and December 31, 1990 on the PC/AT acquisition system, provides station locations, statistics, and calibrations, and outlines which stations were recorded and used in triggering the PC/AT system.

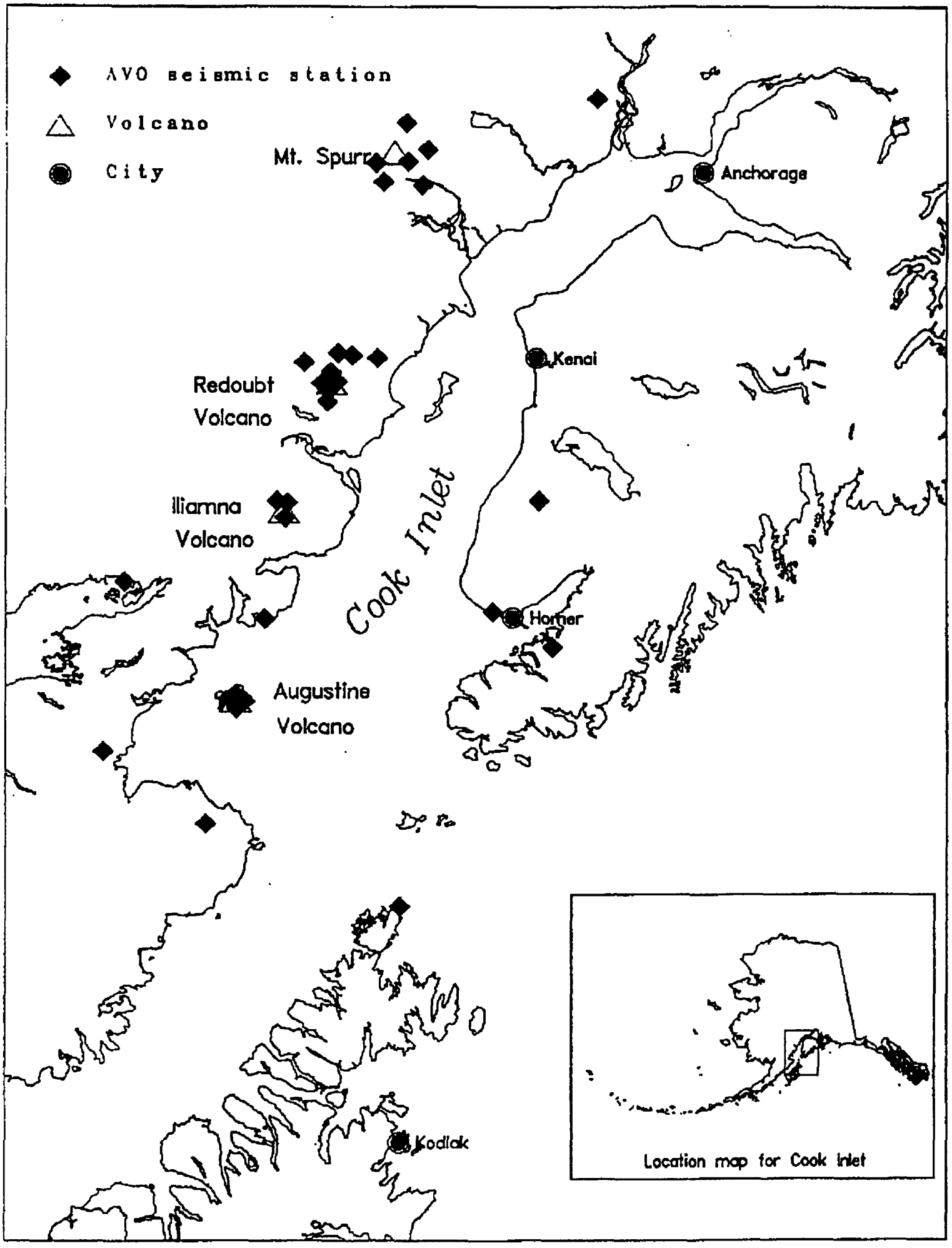


Figure 1. Location of seismic stations operated by the Alaska Volcano Observatory between 1988 and 1990.

## INSTRUMENTATION

In October 1989 six seismic stations, SPU, CRP, CGL, NCG, BGL, and CKL, were in operation around Mt. Spurr (Figure 2). Between October 1989 and February 1990 the Redoubt network consisted of 5 stations; RED, RDN, NCT, DFR, and RDT. RDT was a three-component station with north-south and east-west oriented horizontal instruments. On February 2, 1990 station DRE was installed both to augment monitoring capability at Redoubt Volcano and to aid in monitoring for eruption-related floods in the Drift River valley. In March stations RSO, REF, and RWS were installed on the Redoubt cone to augment the existing network (Figure 3). Station RWS was replaced by station RDW on September 9. On September 10 and 24 two additional stations, RS1 and RS2, were added to form a tripartite array with station RSO. The horizontal instruments at station RDT were moved to station RED on August 30, 1990. Station RDN was disabled as a result of eruptive activity between January 2 - 9, 1990 and February 11 - November 9, 1990. Eruptive activity on December 14, 1989 apparently damaged the RDN seismometer, altering the frequency response. This problem was corrected on November 9, 1990 when the seismometer was replaced. Other stations experienced minor technical trouble and short interruptions in telemetry during the report period. Information on which stations were recorded and used in triggering on the PC/AT system is contained in Appendix B.

AVO seismic stations in the northern portion of Cook Inlet are maintained by the U. S. Geological Survey, and in southern Cook Inlet by the Geophysical Institute (Figure 1). Each institution uses slightly different field equipment. As this report catalogs only hypocenters at Mt. Spurr and Redoubt Volcano, just equipment at and operation of stations at these volcanoes is covered.

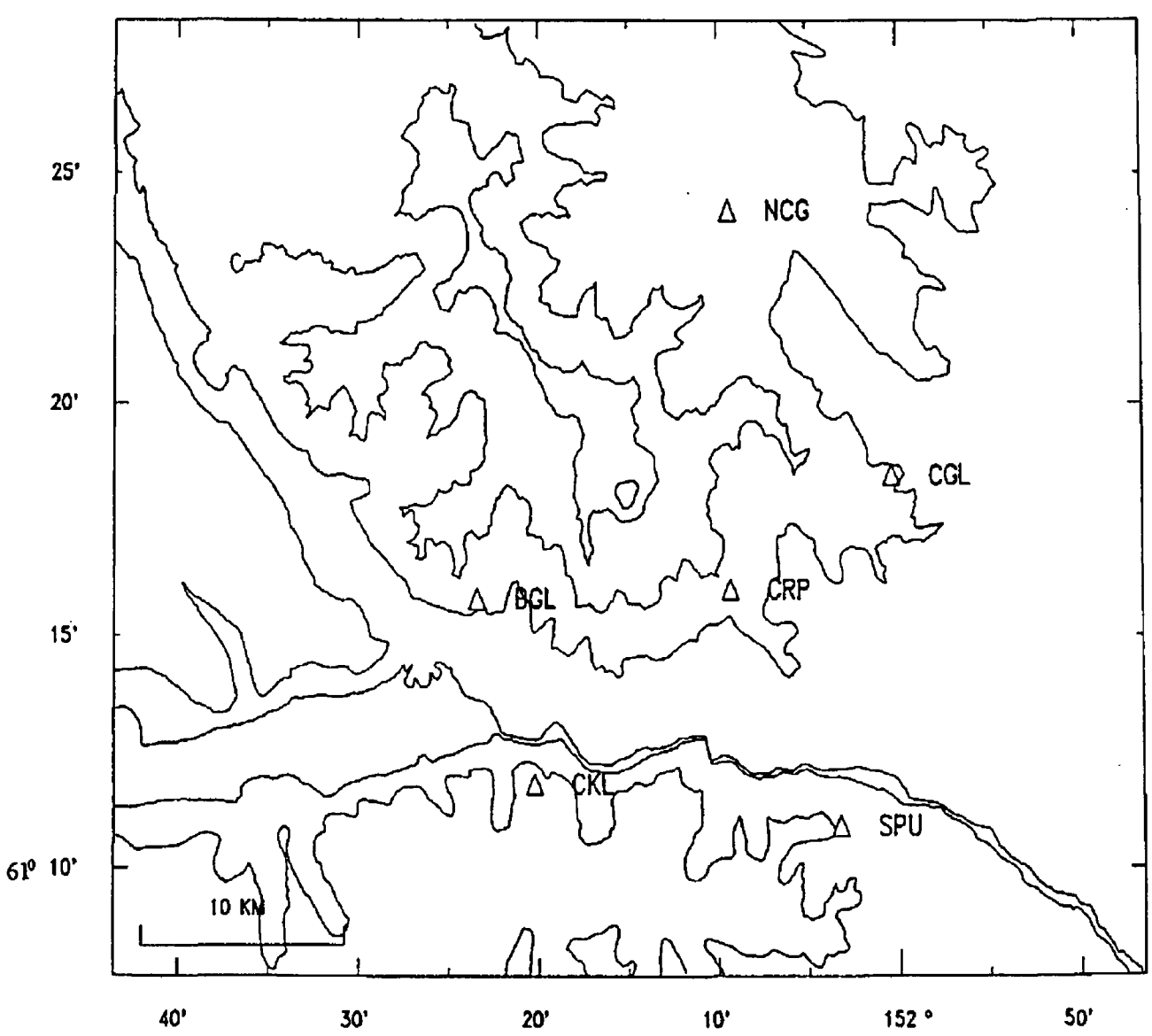


Figure 2. Seismic stations in vicinity of Mt. Spurr.

Stations at Mt. Spurr and Redoubt Volcano consist of a vertical component seismometer with a frequency of 1 HZ (Mark Products L-4C), an A1VCO (Rogers and others, 1980), radio transmitter, antenna, and batteries (which in some cases are float-charged by a solar panel). The two exceptions to this are stations RED and DRE, which differ only in the use of a monitron VCO. Signals from each station are relayed to radio receivers and telemetered via frequency-multiplexed phone lines to the AVO offices in Fairbanks. Appendix C illustrates the response characteristics of the entire system from the seismometer to the computer screen for the various stations.

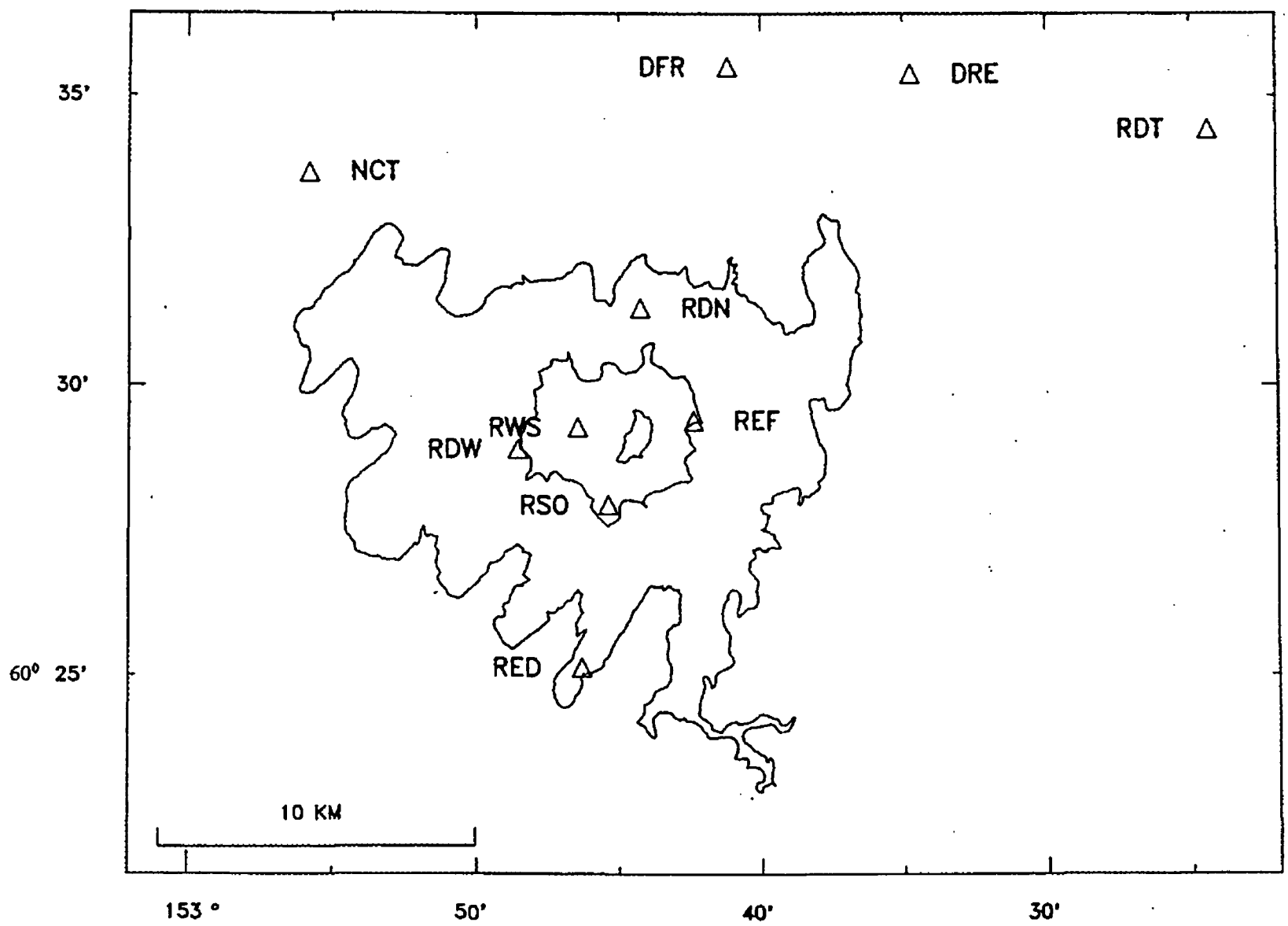


Figure 3. Seismic stations in vicinity of Redoubt Volcano. Stations RS1 and RS2 are not shown.

## DATA ACQUISITION AND REDUCTION

On October 12, 1989 event-triggered recording began on a PC/AT-based seismic data acquisition system (Lee and others, 1989). This system uses the program MDETECT (Lee and others, 1988) to digitize, detect, and record sixteen channels of data. Between October 12, 1989 and December 31, 1990 the system triggered over 12,000 times.

When the PC/AT system was first installed in Fairbanks, the sixteen input channels were distributed evenly among stations on Mt. Spurr, Redoubt Volcano,

and Augustine Volcano. Through the course of the 1989-90 eruption of Redoubt Volcano, input channels were shifted from stations at Augustine and then Mt. Spurr to stations closer to Redoubt Volcano and to new stations added to the Redoubt network. After January 5, 1990, Augustine stations were not recorded on the PC/AT system and after March 10, 1990, stations near Mt. Spurr were not used to trigger event recording.

Recorded events were visually inspected on a computer screen and classified as either a volcano-tectonic earthquake, a long-period event, an explosion event, a regional tectonic earthquake, a teleseismic event, or a non-seismic event. After additional spectral analysis (Lahr, and others, in press), some events at Redoubt Volcano were reclassified as hybrid events (see Power and others, in press, for a description of the various event types). Events were only analyzed for reclassification as hybrids between December 13, 1989 and January 2, 1990. If an event was classified as either a volcano-tectonic or long-period event and had four or more distinct phases at three or more stations, it was selected for location. No attempt was made to locate long-period events with emergent arrivals or low-frequency events in the Spurr area. The initial examination on the computer screen, event classification, the determination of P and S arrival times, direction of first motion, and the period and amplitude of the maximum recorded signal were determined using the program XPICK (Robinson, 1990). Earthquake hypocenters and magnitudes were calculated using the program HYPOELLIPSE (Lahr, 1989). Computed magnitudes approximate the Richter local magnitude as outlined by Eaton and others, (1970). Earthquake depths are computed with respect to sea level, with the negative values reflecting height above sea level.

HYPOELLIPSE expresses the quality of earthquake solutions using a number of parameters which include: RMS (the root mean square residual); SEH (the 68 percent confidence limit in the least well-constrained direction); SEZ (the 68 percent confidence limit in depth); GAP (the largest azimuthal separation between stations measured from the epicenter); NP, the number of P arrivals used in the solution; and NS, the number of S arrivals used in the solution. More detailed information on these parameters is given by Lahr (1989). A complete discussion of the earthquake location process is given by Lee and Stewart (1981).

Earthquake hypocenter determinations contain both systematic and random errors. Systematic errors can result from errors in the velocity model, misidentification of phases, or systematic timing errors. Systematic errors affect the accuracy of the hypocenter determination and can be evaluated through controlled experiments such as locating man-made explosions. Random errors result from timing errors and are estimated for each earthquake through the use of standard

statistical techniques. Random errors affect the precision with which hypocenters can be calculated.

The quality of each solution was checked using a computer algorithm which identifies those events without magnitude, fewer than three P phases, fewer than one S phase, or SEH or SEZ greater than 15.0 km. Additionally all events at Redoubt Volcano with depths greater than 10 km and volcano-tectonic events with depths less than 4 km were reinspected. Corrections were made as required.

## VELOCITY MODELS

For earthquakes which occur at Mt. Spurr, the velocity model used to calculate hypocenters is:

| LAYER | DEPTH (TO TOP OF LAYER) | P VELOCITY (km/s) | VP/VS (km/s) |
|---|---|---|---|
| 1 | -3.2 | 5.1 | 1.81 |
| 2 | -2.2 | 5.5 | 1.81 |
| 3 | -5.05 | 6.3 | 1.74 |

Depths are referenced to sea level, with negative values reflecting height above sea level. Below 27.05 km depth this model is underlain by a uniform halfspace with P-wave velocity of 7.2 km/s and VP/VS of 1.78 km/s. Station corrections for use with this model are shown below:

| STATION | P-DELAY (Seconds) | S-DELAY (Seconds) |
|---|---|---|
| BGL | -0.12 | 0.00 |
| BRLK | -0.62 | -1.20 |
| CGL | 0.04 | -0.11 |
| CKL | 0.07 | 0.00 |
| CNP | -0.44 | 0.00 |
| CRP | 0.11 | 0.00 |
| CUT | 0.41 | 0.00 |
| DFR | -0.37 | -0.77 |
| GHO | 0.36 | 0.00 |
| ILM | -0.63 | -1.40 |
| KNK | -0.85 | -0.54 |
| NCT | -0.24 | -0.66 |
| NKA | 2.18 | 0.00 |
| NNL | 1.21 | 0.00 |
| PME | 0.18 | 0.00 |
| RDN | -0.42 | -0.69 |
| RDT | -0.49 | -0.88 |
| RED | -0.43 | -1.00 |
| SKL | -0.20 | -0.80 |
| SLV | -1.10 | 0.00 |
| SPU | 0.04 | -0.06 |
| SVW | 0.00 | -0.65 |

The Spurr model was derived by minimizing the average root-mean-square (rms) residual of observed versus computed travel times (Jolly and others,1991).

At Redoubt Volcano the velocity model used is:

| LAYER | DEPTH (TO TOP OF LAYER) | P VELOCITY (km/s) | VP/VS(km/s) |
|---|---|---|---|
| 1 | -3.00 | 2.9 | 1.80 |
| 2 | -1.70 | 5.1 | 1.80 |
| 3 | 1.50 | 6.4 | 1.72 |

In this model depths are referenced to sea level; negative values reflect height above sea level. Below 17 km depth this model is underlain by a uniform halfspace with P-wave velocity of 7.0 km/s and a VP/VS ratio of 1.780. Station corrections for use with this model are shown below:

| STATION | P-DELAY (Seconds) | S-DELAY (SECONDS) |
|---|---|---|
| DFR | 0.00 | -0.10 |
| DRE | 0.00 | 0.00 |
| NCT | 0.00 | 0.06 |
| RDN | -0.01 | -0.04 |
| RDT | 0.00 | -0.02 |
| RDTE | 0.00 | -0.02 |
| RDTN | 0.00 | -0.02 |
| RDW | 0.02 | -0.12 |
| REF | 0.01 | 0.00 |
| RED | -0.02 | -0.05 |
| REDE | -0.02 | -0.05 |
| REDN | -0.02 | -0.05 |
| RSO | 0.00 | 0.00 |
| RS1 | 0.00 | 0.00 |
| RS2 | 0.00 | 0.00 |

S phases at DFR, RDN, REF, RS1, RS2, and RSO are not used. S phases at the remaining stations are used with reading errors set to 0.14 seconds. This model was derived by Lahr and others, (in press) by minimizing the average root-mean-square (rms) residual of observed versus computed travel times and developing station corrections based on explosion data collected during the summer of 1991.

## DISCUSSION

Origin times, focal coordinates, magnitudes, and related parameters for 9877 earthquakes from October 12, 1989 through December 31, 1990 are contained in a file on the accompanying floppy disk. Epicenters of 144 of these events occur with 20 km of the summit of Mt. Spurr (Figure 4). The remaining 9733 earthquakes occur in the vicinity of Redoubt Volcano and are associated with the 1989-90 eruption (Power and others, in press).

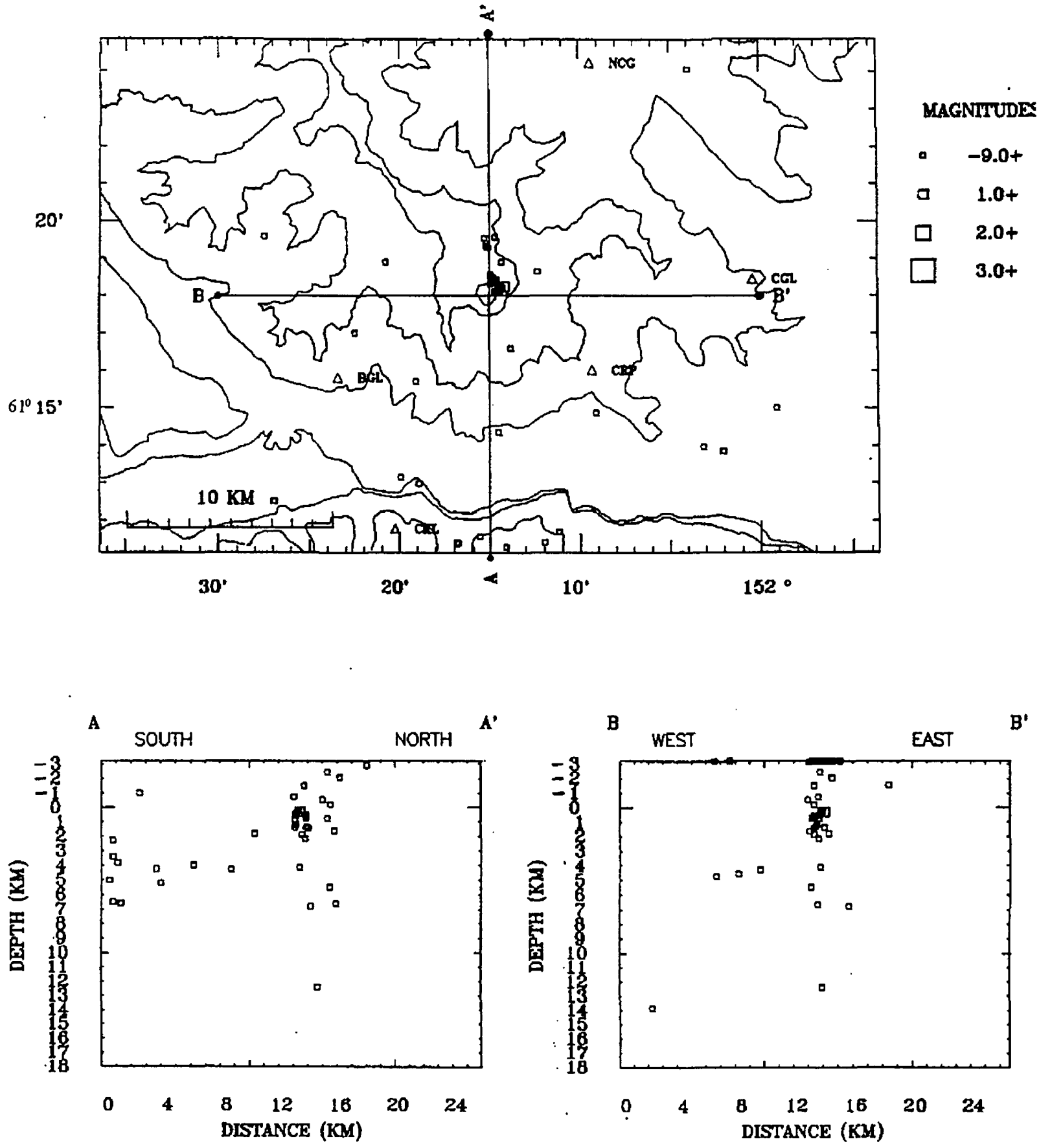


Figure 4. Epicenter map and cross sections for Mt. Spurr from October 12, 1989 through March 10, 1990.

Earthquakes located at Mt. Spurr by the PC/AT system form a dominant cluster beneath the summit of Mt. Spurr. Events in this cluster are shallow and range from -3.0 to 1.0 km depth. This cluster of events is a long-standing feature of seismic activity at Mt. Spurr (Jolly, and others, 1991). Magnitudes of located events at Mt Spurr ranged from -0.6 to 2.7 during the report period. In March 1990 stations on the PC/AT system were shifted from stations in the Mt. Spurr network to new stations at Redoubt Volcano. The PC/AT system did not trigger on stations in the Mt. Spurr network for the remainder of the report period.

At Redoubt Volcano a few small earthquakes were located during October and November 1989. A vigorous swarm of long-period earthquakes occurred in the 23-hour period prior to the onset of the 1989-90 eruption on December 14, 1989. Shallow swarms (-3 to 1 km depth) of volcano-tectonic earthquakes followed explosive events on December 15 and 19. A deeper swarm of volcano-tectonic earthquakes was initiated by explosive events on December 15. This deeper swarm increased in intensity in late December and declined gradually through the remainder of the eruption. Additional swarms of long-period events are described by Stephens and others, (in press). Generally only those long-period events which occurred during swarms on December 13 - 14 and December 26, 1989 - January 2, 1990 were large enough to locate. A map of earthquake epicenters for Redoubt Volcano is shown in Figure 5. A plot of focal depth versus time of all located events in the Redoubt network between October 12, 1989 and December 31, 1990 is shown in Figure 6. For more detailed descriptions and analysis of the seismicity accompanying the 1989-90 eruption of Redoubt Volcano see Chouet and others, (in press), Lahr and others, (in press), Power and others, (in press), and Stephens and others, (in press).

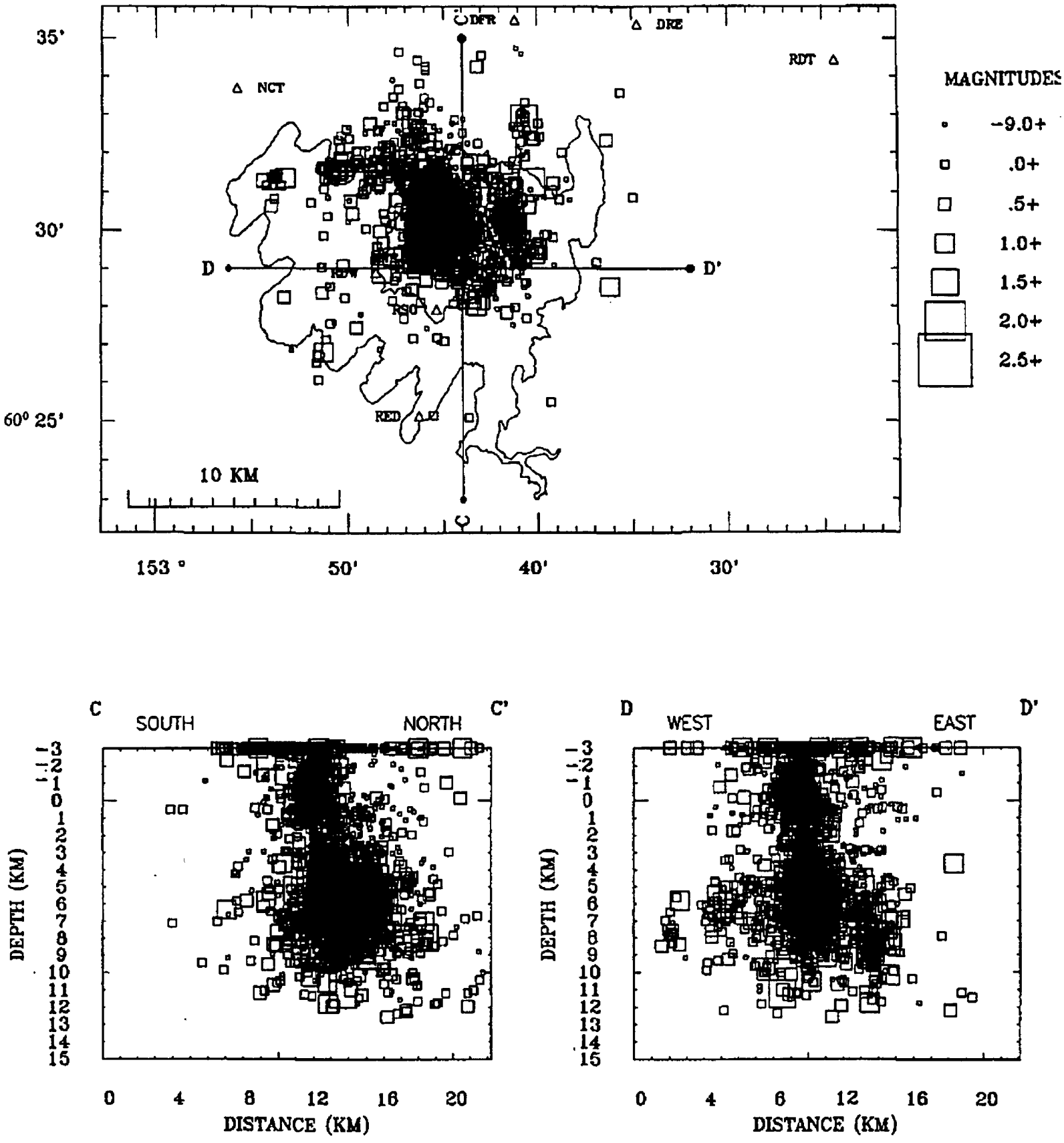


Figure 5. Epicenters map and cross sections for Redoubt Volcano from October 12, 1989 through December 31, 1990.

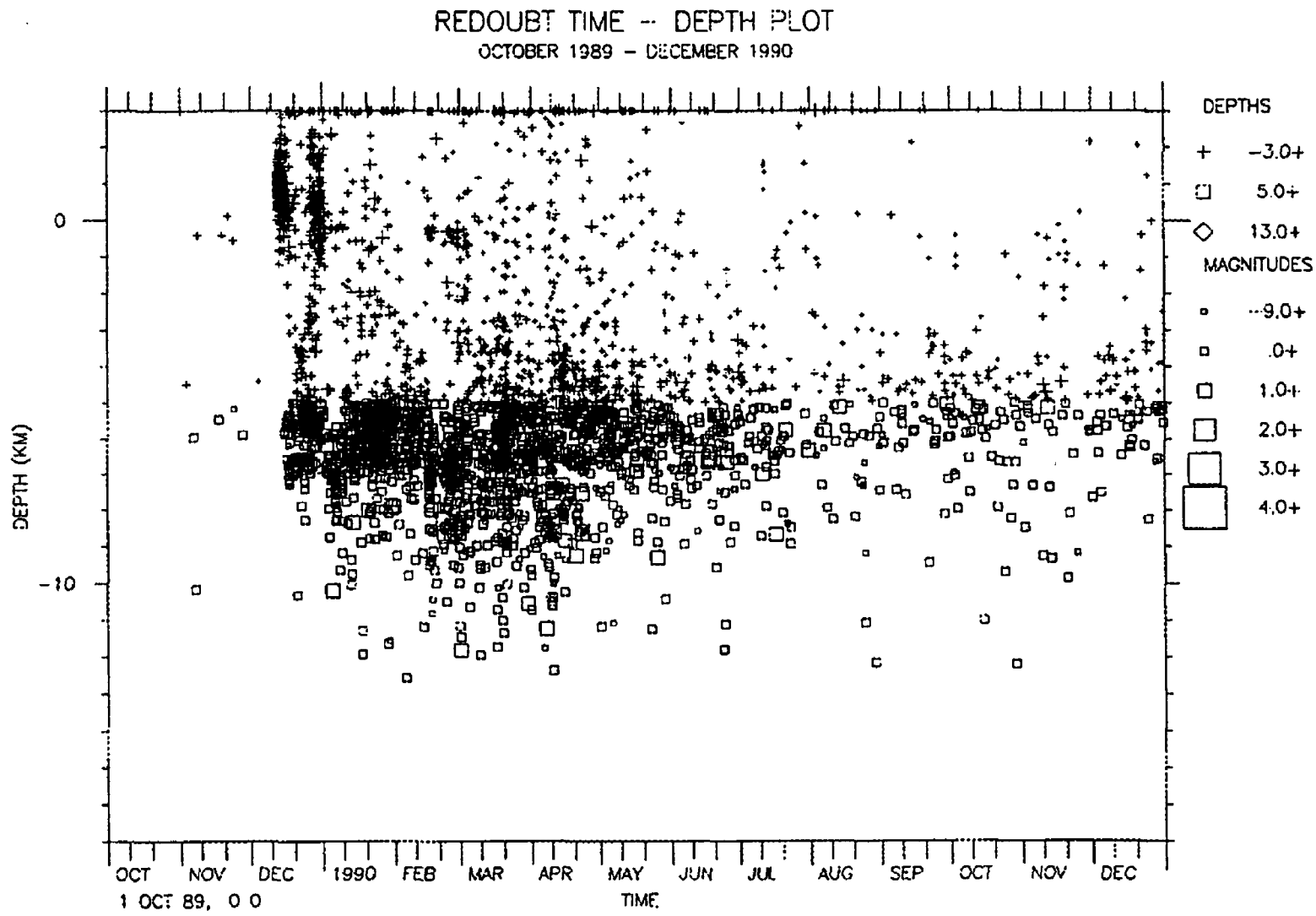


Figure 6. Focal depth versus time for all located events in the Redoubt network between October 12, 1989 and December 31, 1990.

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# APPENDIX A

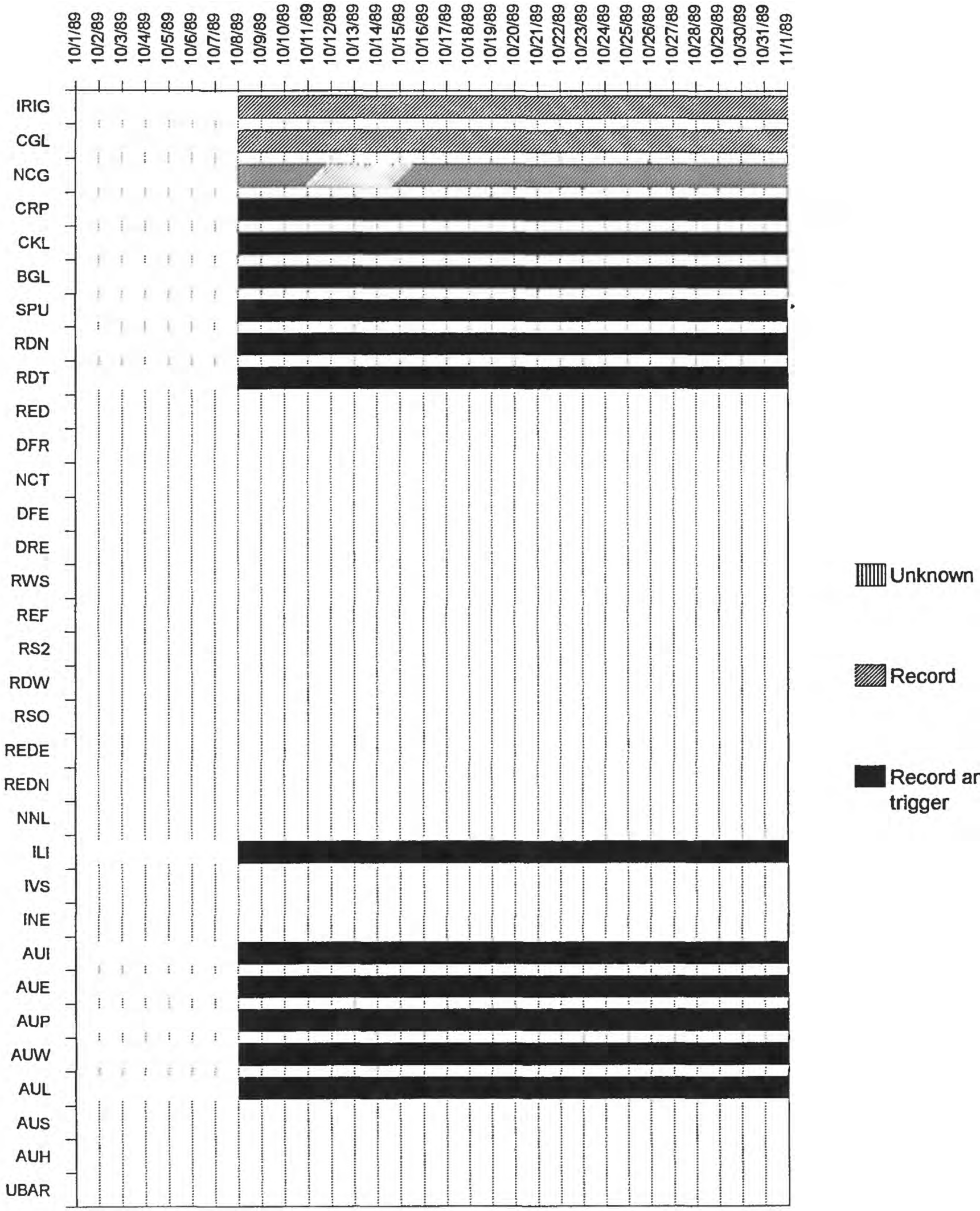
Appendix A lists stations operated by the Alaska Volcano Observatory in the Cook Inlet region between October, 1989 and December, 1990. The list includes geographic coordinates, elevation, installation date, and organization responsible for maintenance for each station.

| Station | Latitude | Longitude | Elevation (m) | Installation date | Maintainer |
|---|---|---|---|---|---|
| BGL | 61.2635 | -152.3905 | 1173 | 890813 | USGS |
| CGL | 61.3077 | -152.0067 | 1082 | 810922 | USGS |
| CKL | 61.1965 | -152.3378 | 1265 | 890805 | USGS |
| CKN | 61.2073 | -152.1815 | 735 | 910819 | USGS |
| CRP | 61.2670 | -152.1555 | 1622 | 810826 | USGS |
| NCG | 61.4037 | -152.1567 | 1244 | 890806 | USGS |
| SPU | 61.1817 | -152.0543 | 800 | 710810 | USGS |
| REF | 60.4892 | -152.7017 | 1801 | 900314 | USGS |
| RDN | 60.5230 | -152.7385 | 1372 | 880813 | USGS |
| RDW | 60.4827 | -152.8095 | 1813 | 900907 | USGS |
| RS1 | 60.4602 | -152.7580 | 1864 | 900910 | USGS |
| RS2 | 60.4630 | -152.7573 | 1953 | 900910 | USGS |
| RSO | 60.4622 | -152.7538 | 1921 | 900301 | USGS |
| RED | 60.4190 | -152.7720 | 1067 | 740000 | USGS |
| REDE | 60.4190 | -152.7720 | 1067 | 900830 | USGS |
| REDN | 60.4190 | -152.7720 | 1067 | 900830 | USGS |
| REDL | 60.1490 | -152.7720 | 1067 | 900830 | USGS |
| RWS | 60.4880 | -152.7745 | 2713 | 900315 | USGS |
| DFR | 60.5920 | -152.6862 | 1097 | 880815 | USGS |
| DRE | 60.5832 | -152.5868 | 489 | 900201 | USGS |
| NCT | 60.5617 | -152.9297 | 1166 | 880814 | USGS |
| RDT | 60.5738 | -152.4062 | 930 | 710809 | USGS |
| RDTN | 60.5738 | -152.4062 | 930 | 710809 | USGS |
| RDTE | 60.5738 | -152.4062 | 930 | 710809 | USGS |
| INE | 60.0608 | -153.6250 | 1585 | 900829 | UAGI |
| INW | 60.0677 | -153.1325 | 1219 | 900829 | UAGI |
| IVS | 60.0092 | -153.0808 | 2332 | 900829 | UAGI |
| AUH | 59.3638 | -153.4435 | 900 | 781201 | UAGI |
| AUI | 59.3352 | -153.4277 | 293 | 780406 | UAGI |
| AUIE | 59.3352 | -153.4277 | 293 | 860600 | UAGI |
| AUIN | 59.3352 | -153.4277 | 293 | 860600 | UAGI |
| AUP | 59.3623 | -153.4205 | 1033 | 870922 | UAGI |
| AUS | 59.3600 | -153.4307 | 1226 | 900901 | UAGI |
| AUW | 59.3670 | -153.4708 | 320 | 860700 | UAGI |
| AUE | 59.3590 | -153.3722 | 172 | 870830 | UAGI |
| AUL | 59.3822 | -153.4345 | 360 | 801029 | UAGI |
| CDD | 58.9298 | -153.6430 | 622 | 810817 | UAGI |
| SKN | 61.9803 | -151.5297 | 564 | 720808 | USGS |
| NNL | 60.0443 | -151.2893 | 381 | 720824 | USGS |
| CNP | 59.5258 | -151.2360 | 564 | 830701 | USGS |

| Station | Latitude | Longitude | Elevation (m) | Installation date | Maintainer |
|---|---|---|---|---|---|
| HOM | 59.6583 | -151.6433 | 198 | 760800 | UAGI |
| PDB | 59.7878 | -154.1925 | 305 | 780909 | UAGI |
| OPT | 59.6527 | -153.2297 | 450 | 740000 | UAGI |
| PDB | 59.7878 | -154.1925 | 305 | 780909 | UAGI |
| MMN | 59.1852 | -154.3367 | 442 | 810822 | UAGI |
| BGM | 59.3927 | -155.2293 | 625 | 780908 | UAGI |
| SHU | 58.6280 | -152.3488 | 34 | 740000 | UAGI |
| XLV | 59.4547 | -151.6717 | 320 | 870916 | UAGI |

# APPENDIX B

Appendix B shows stations being recorded on the PC/AT acquisition system on a daily scale for the period October 8, 1989 through December 31, 1990. The period from October 8, 1989 through December 11, 1989 is not well documented, as few events were recorded during this period. The period from December 12, 1989 through December 31, 1990 is well documented. Different patterns are used to distinguish whether stations were used in event triggering or were only recorded.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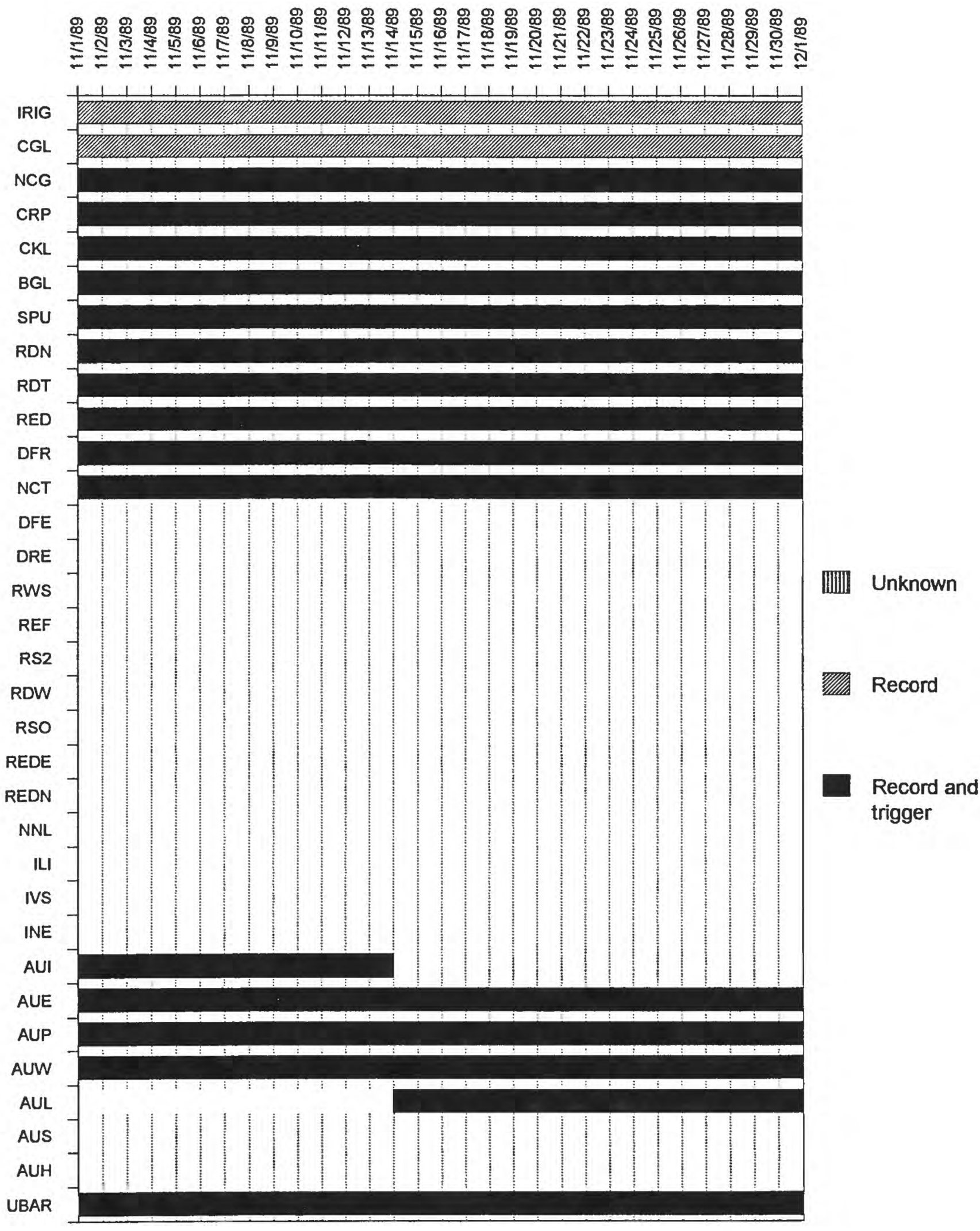
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AUI
AUE
AUP
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AUL
AUS
AUH
UBAR
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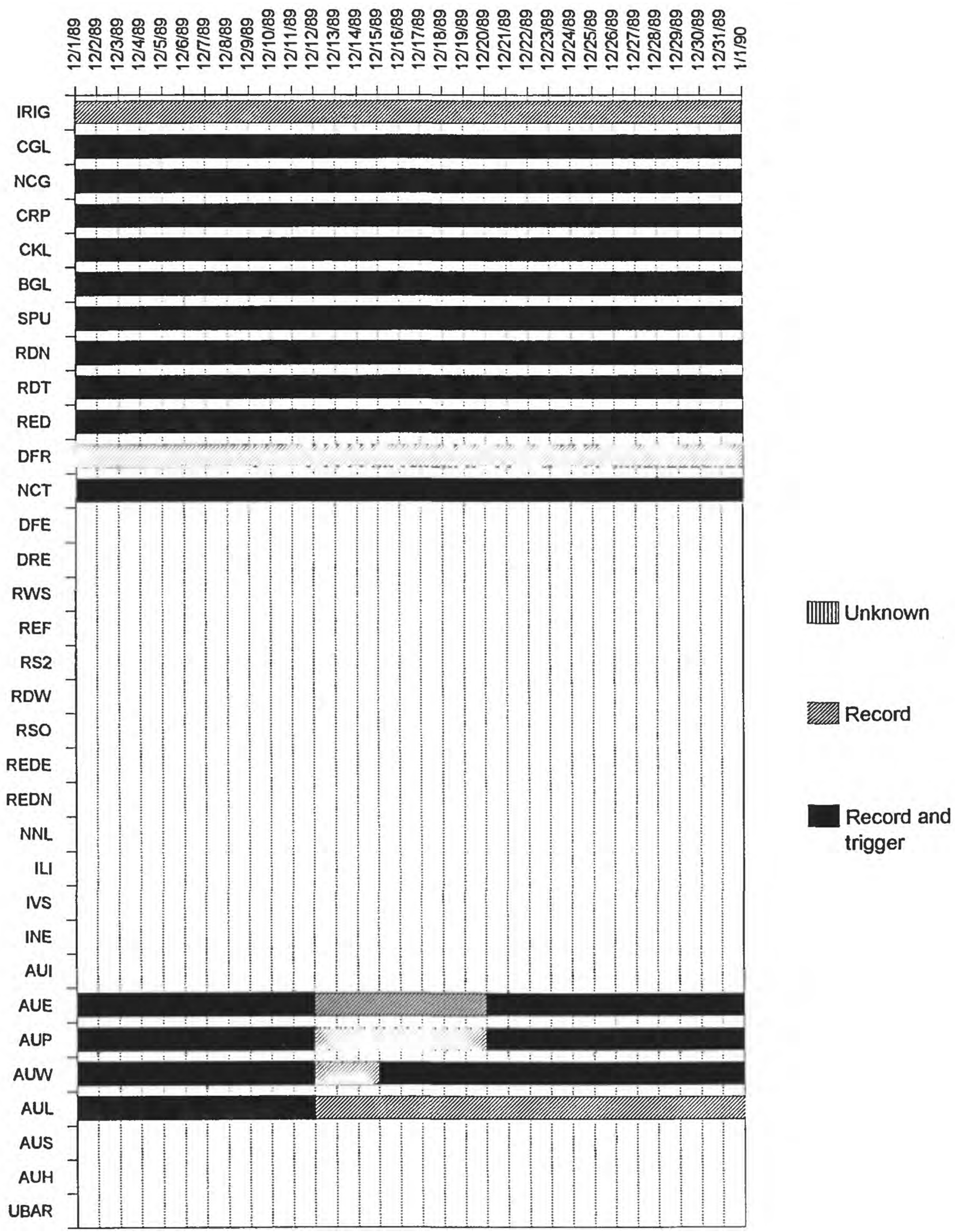
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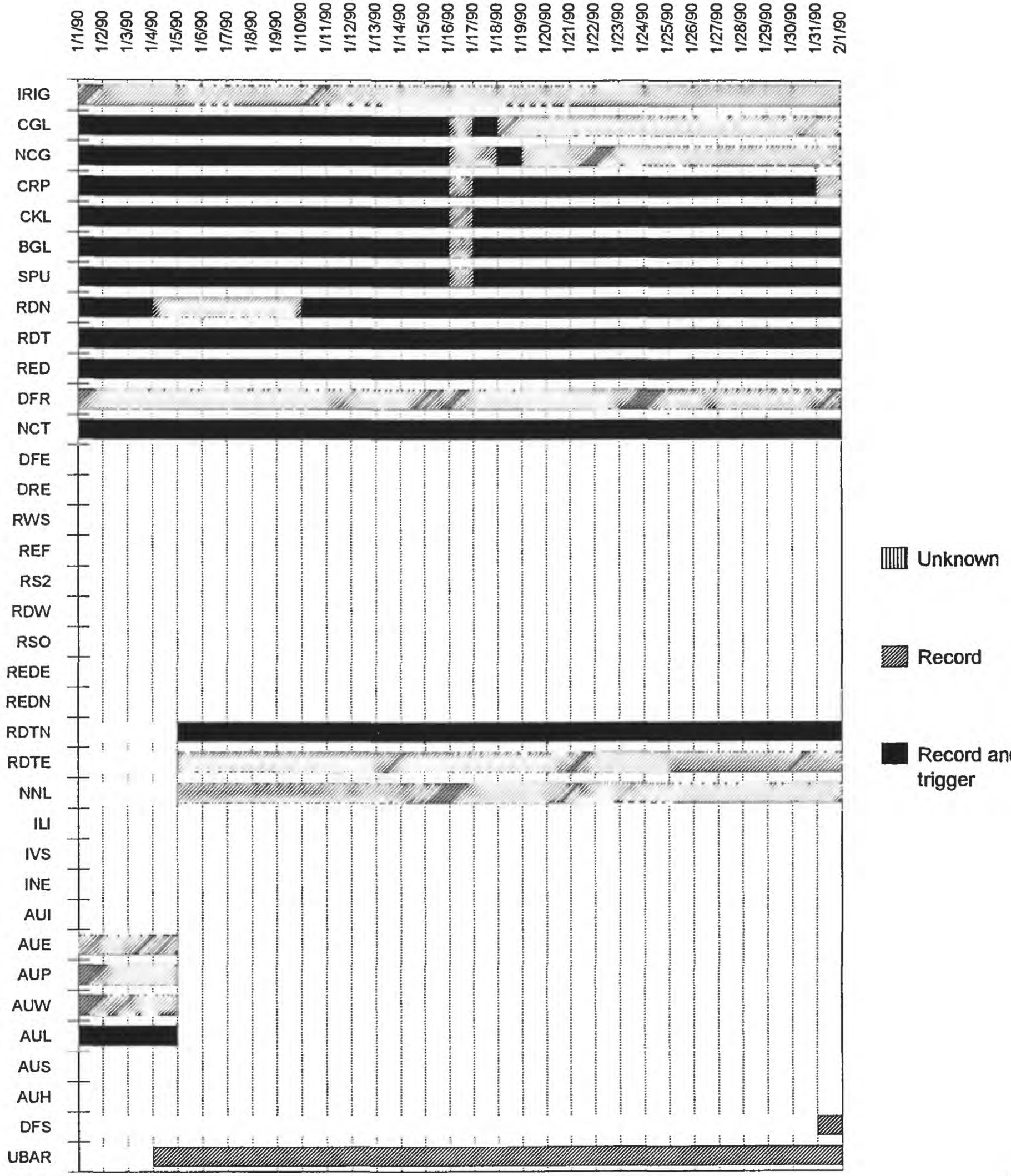
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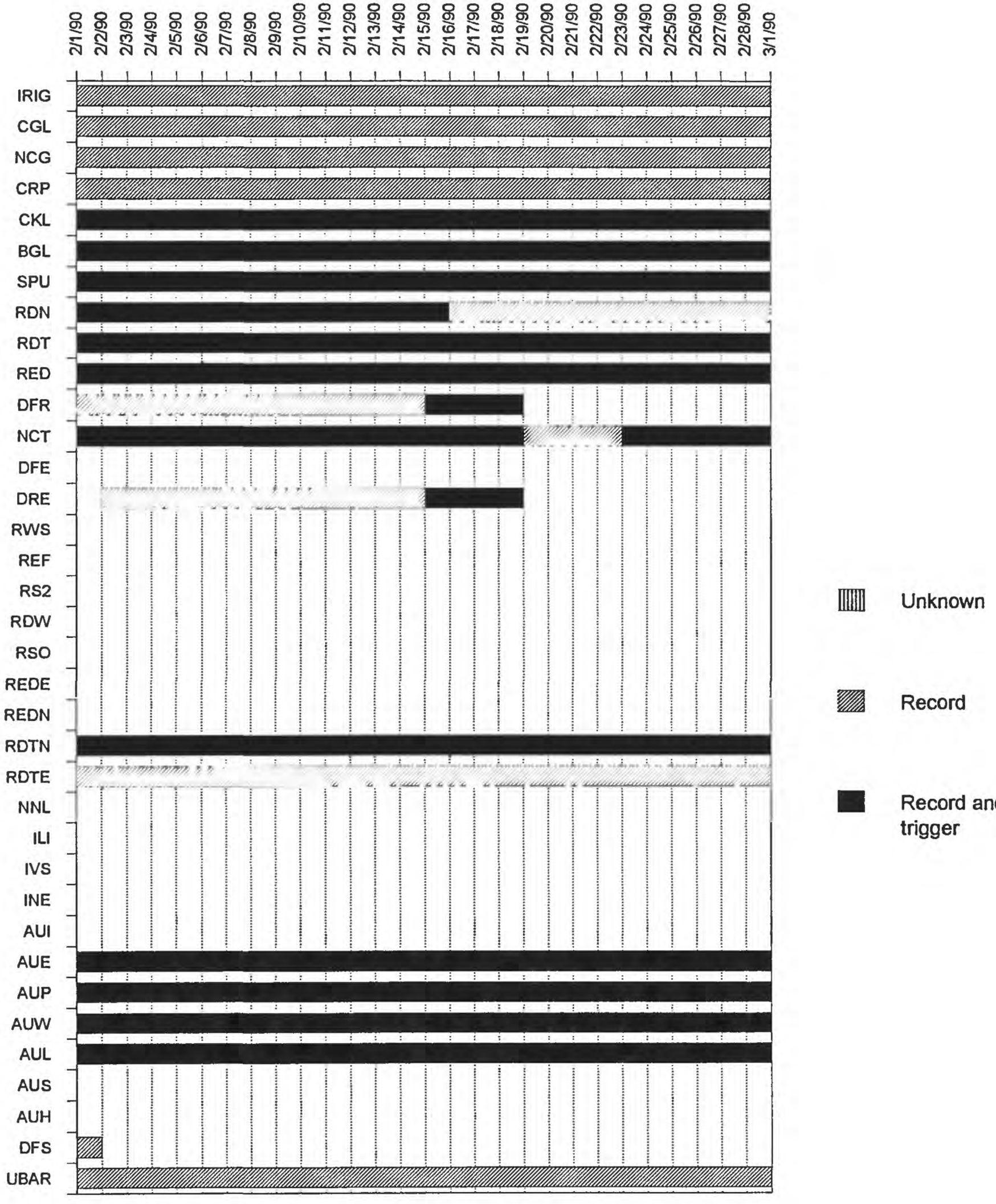
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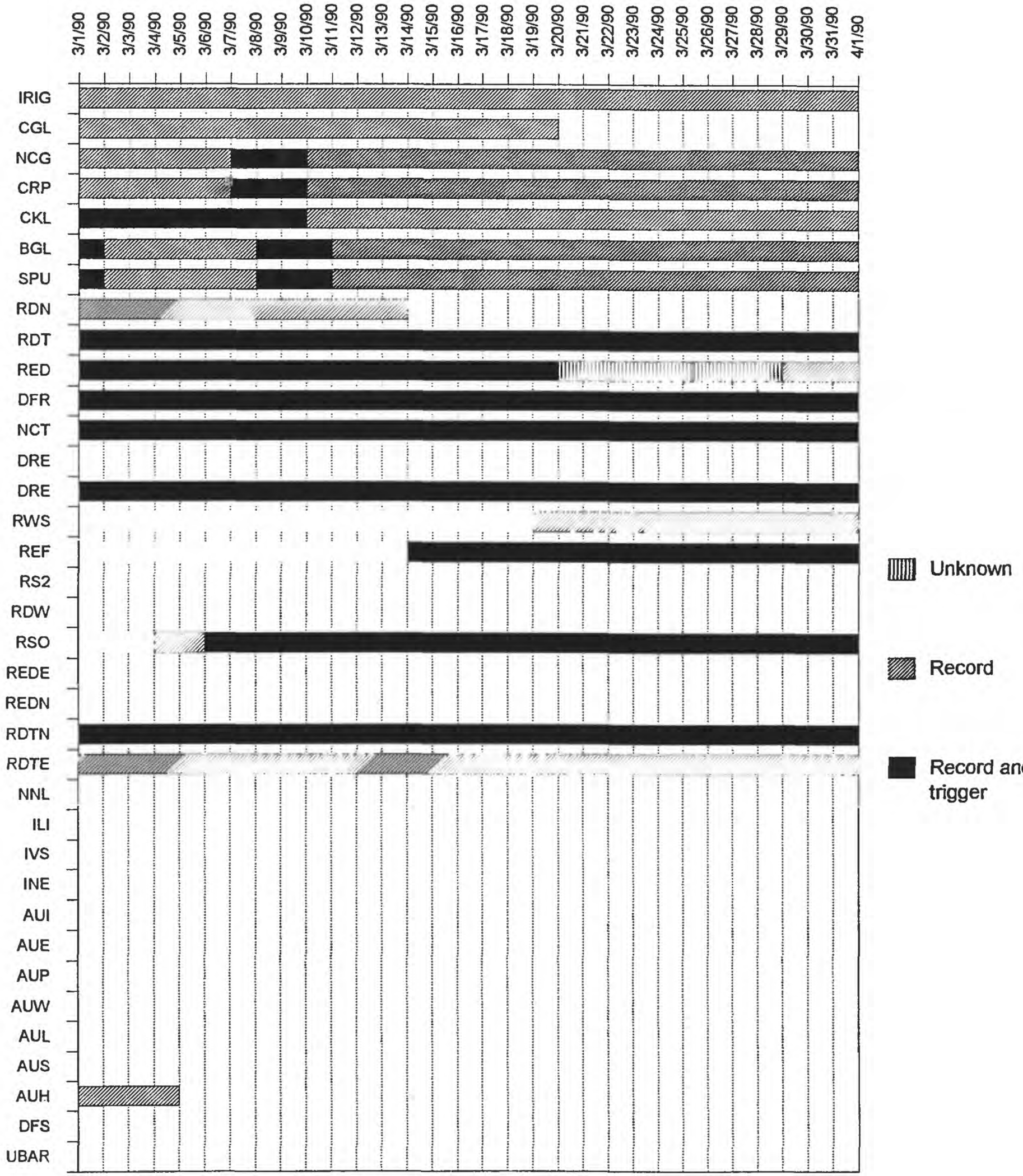
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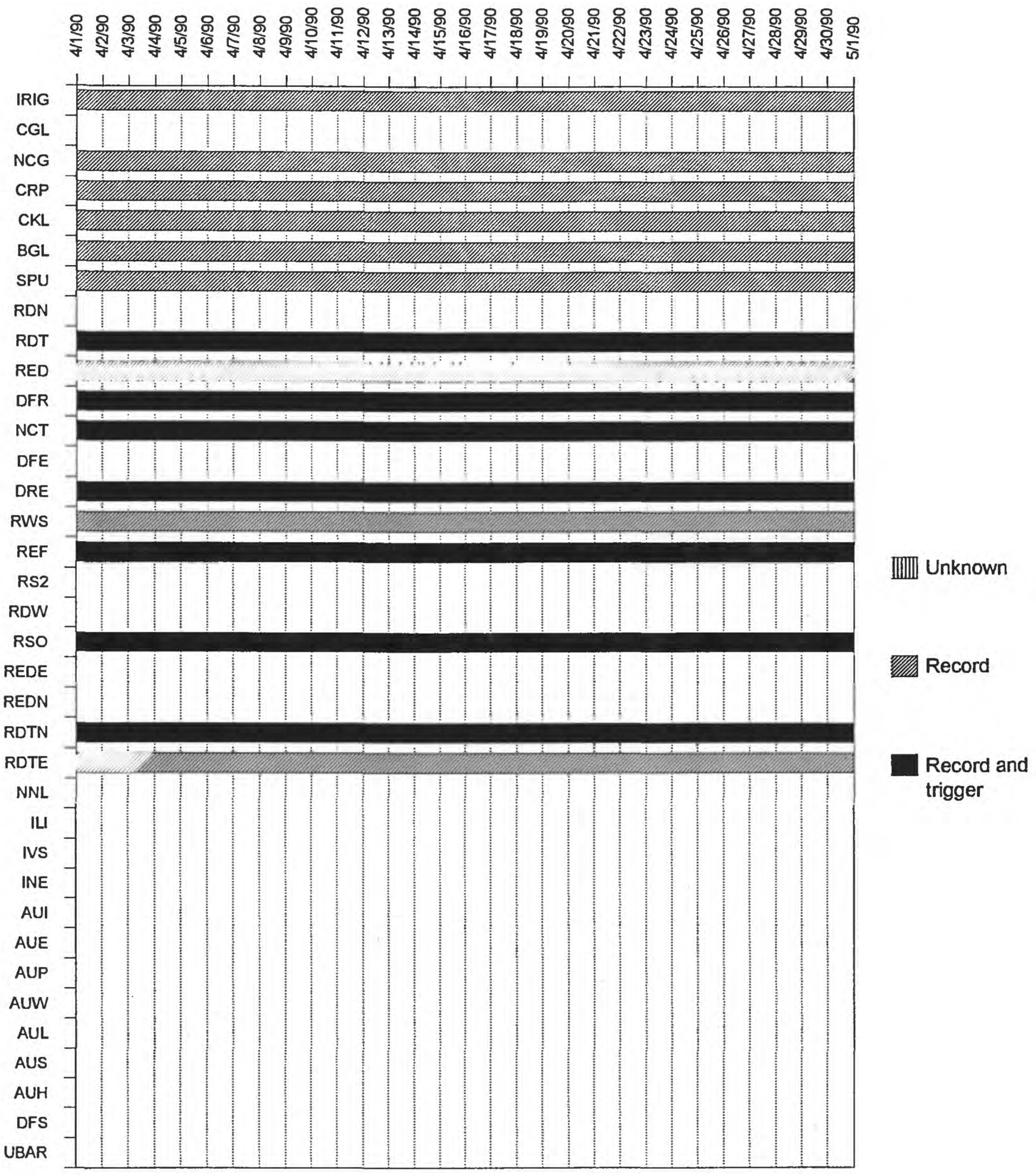
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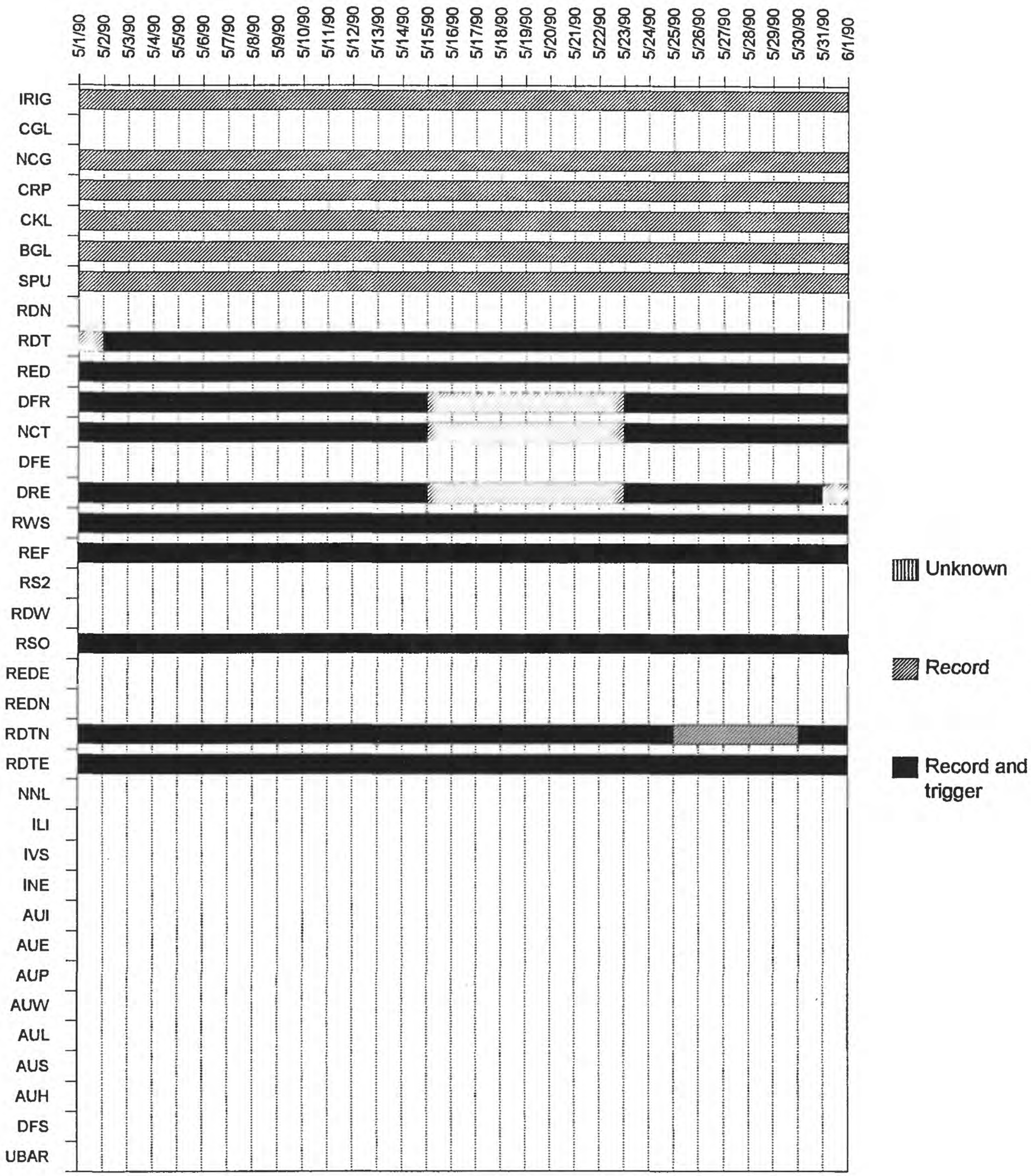
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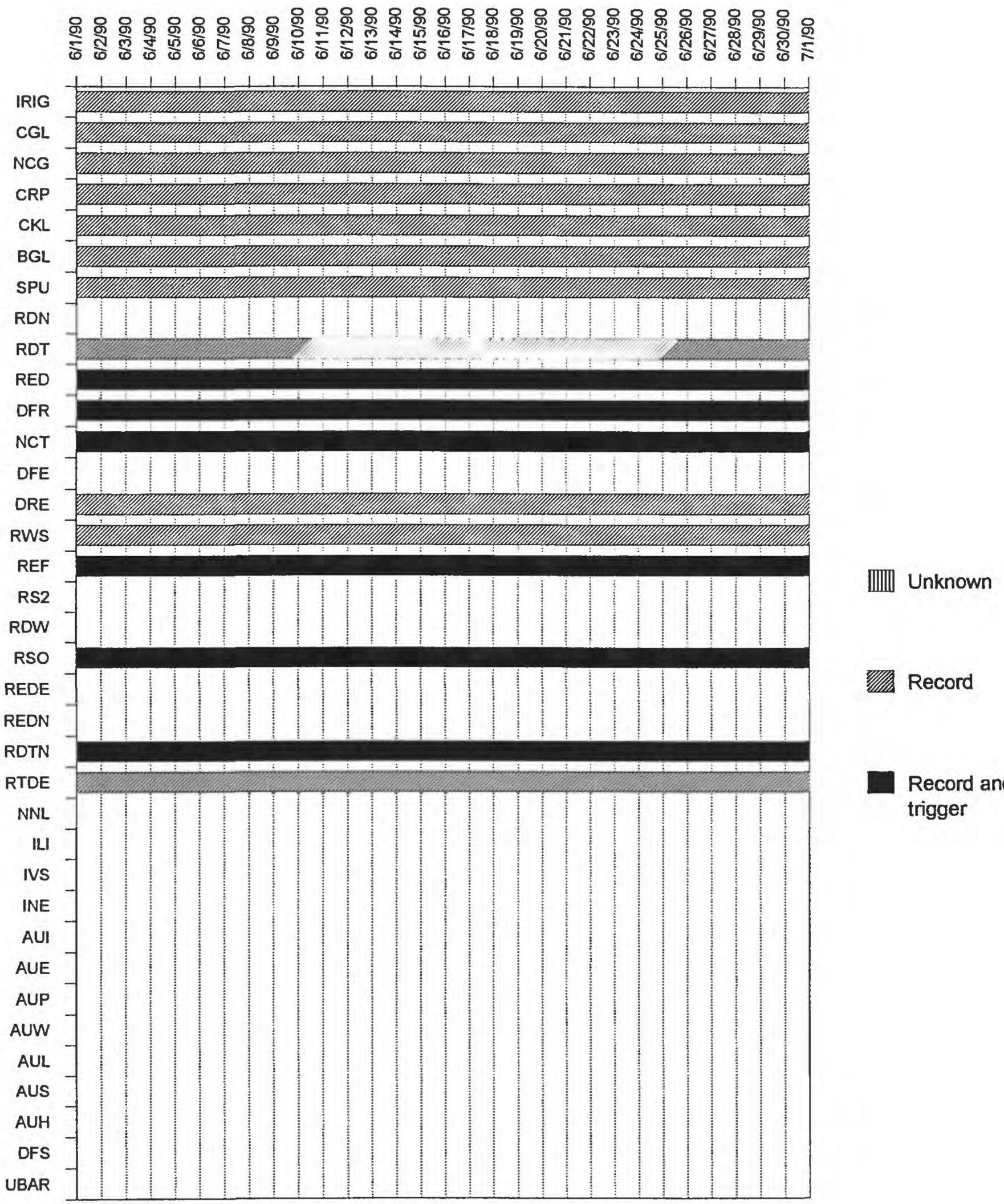
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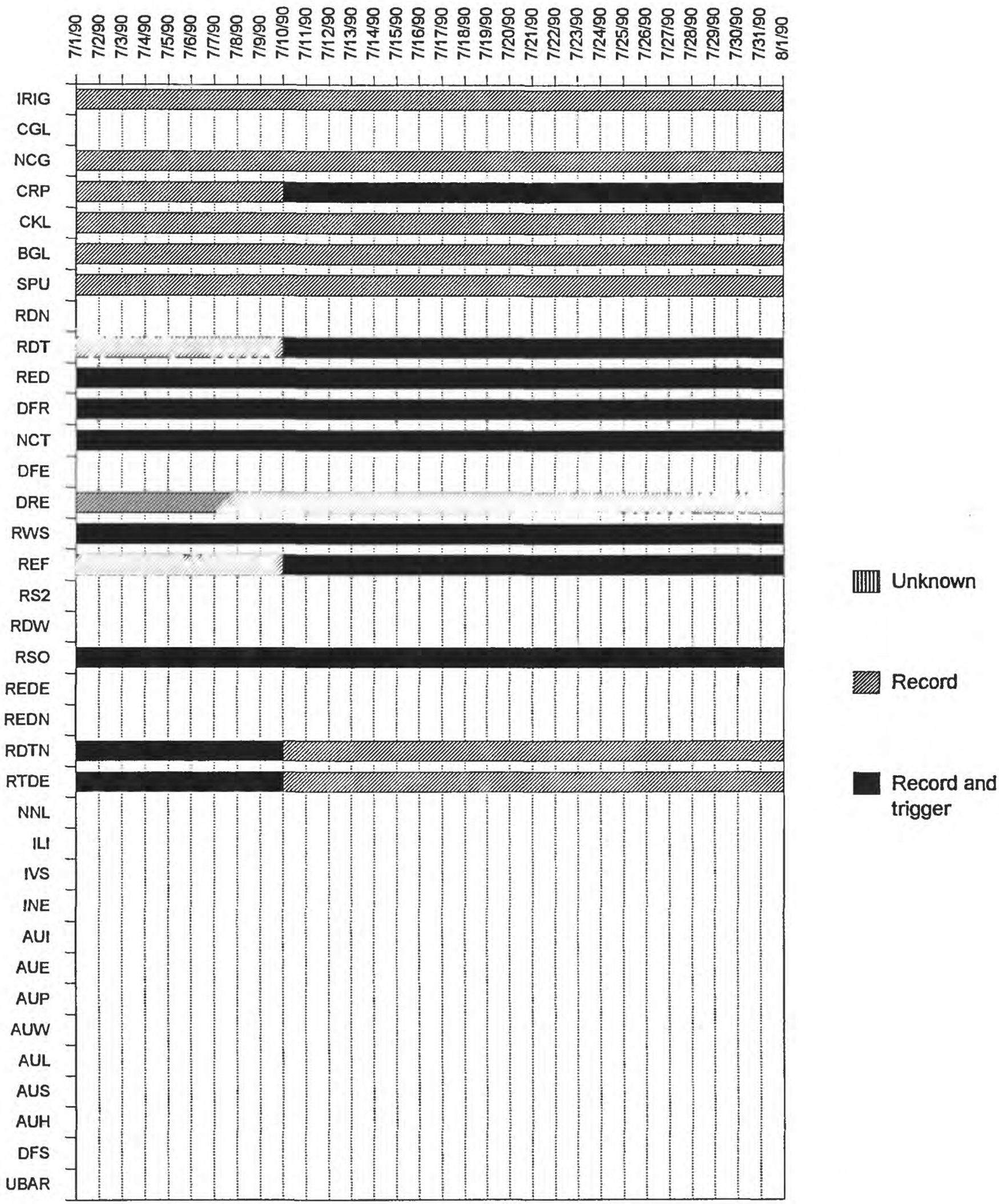
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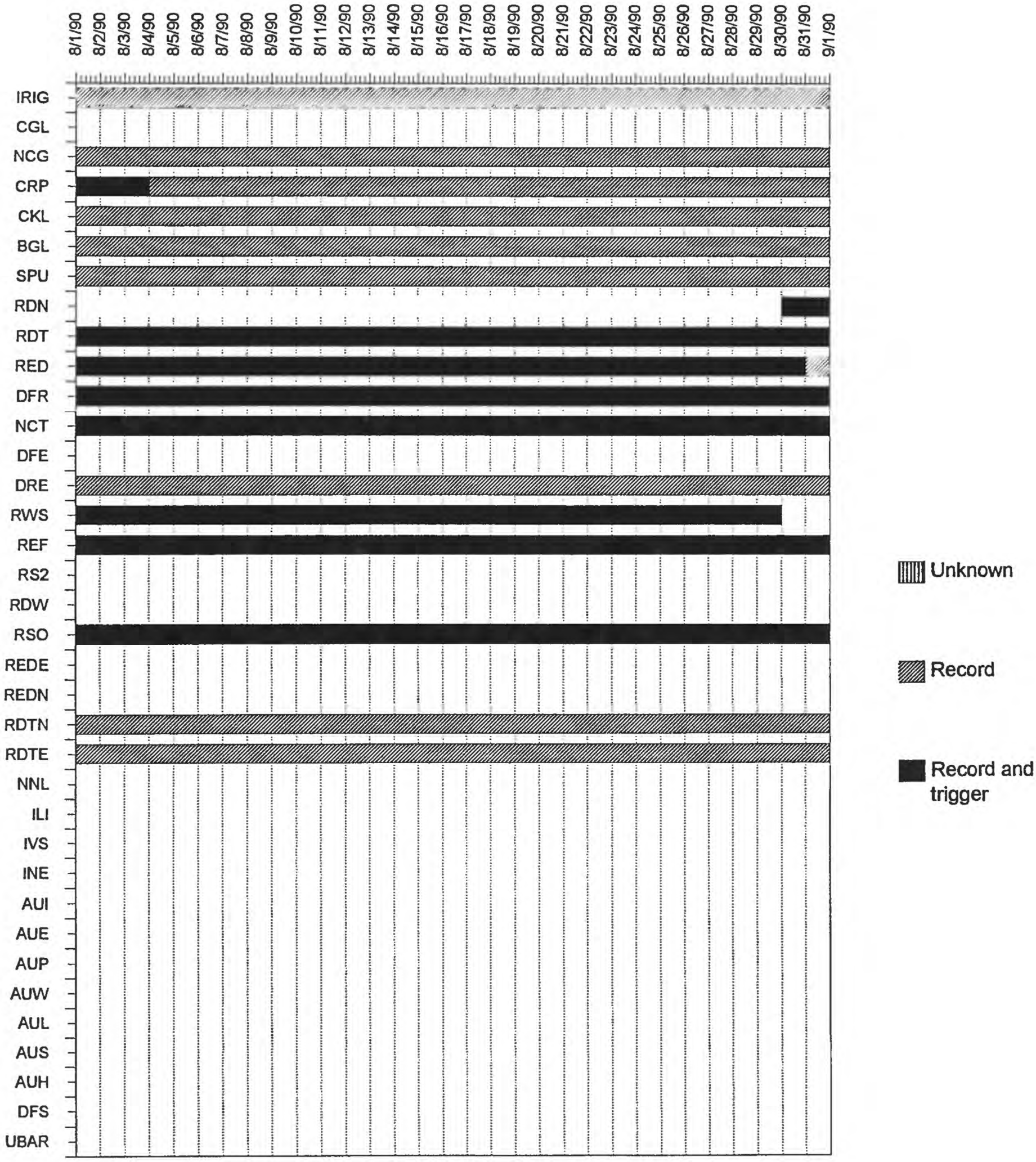
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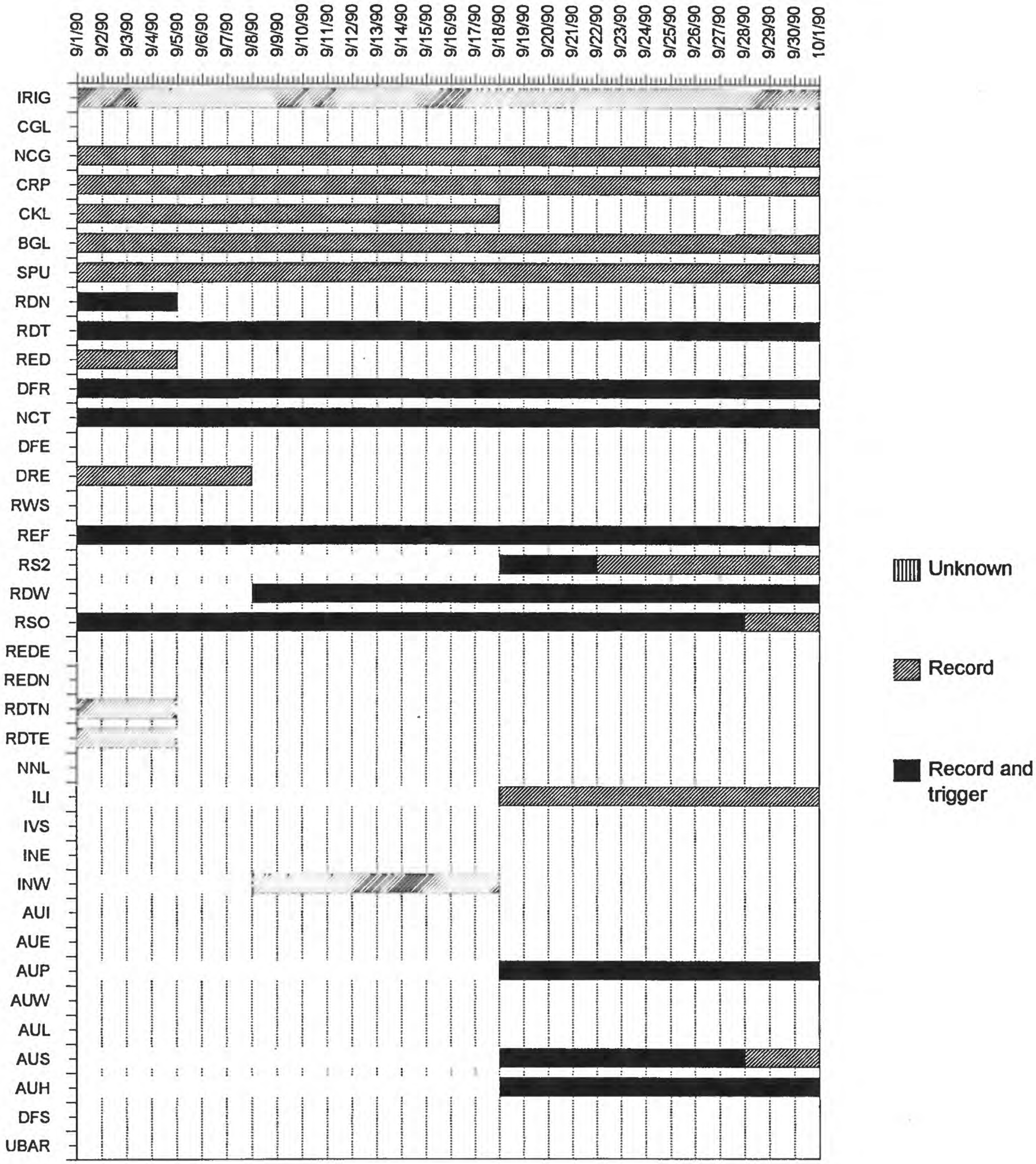
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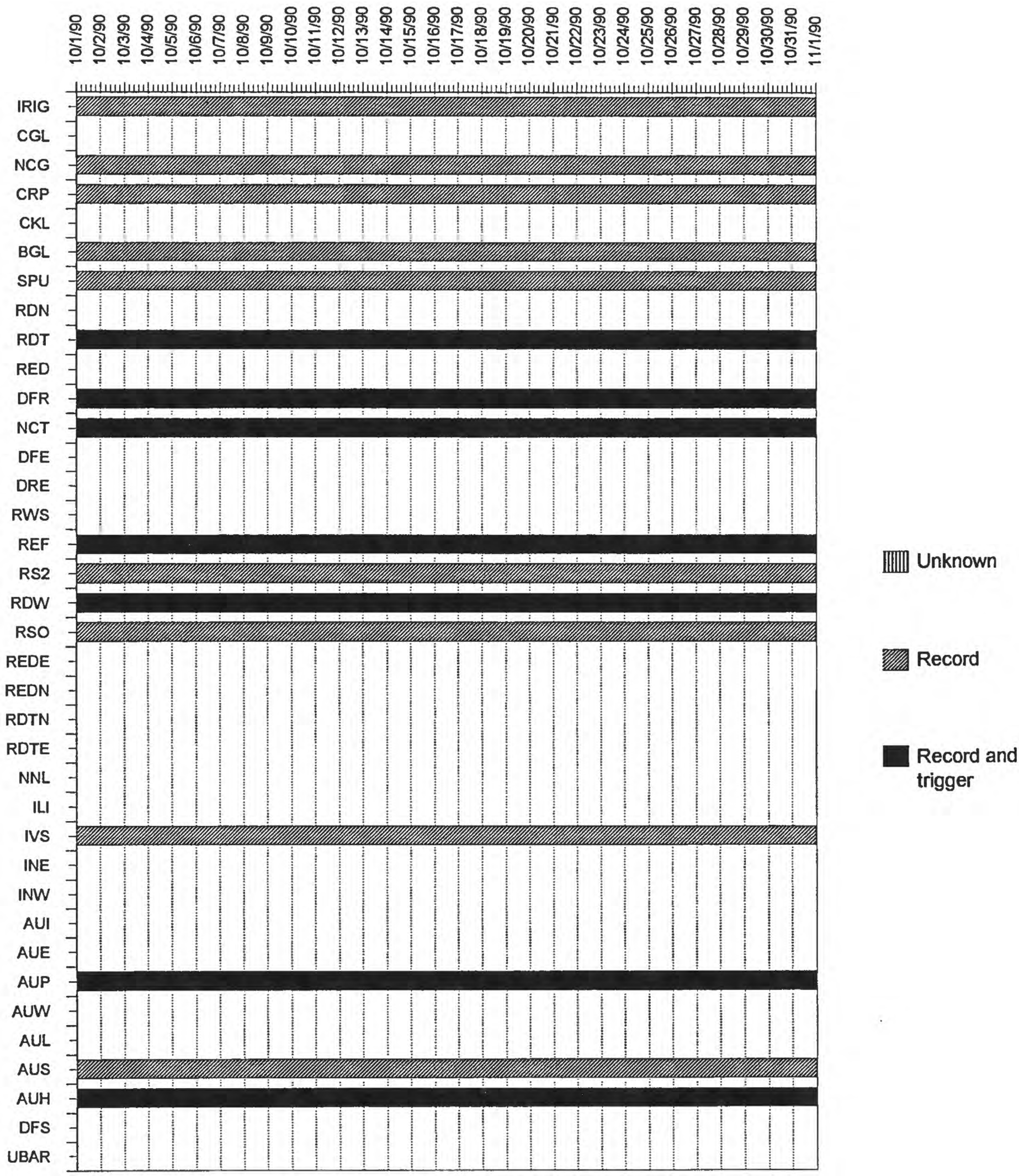
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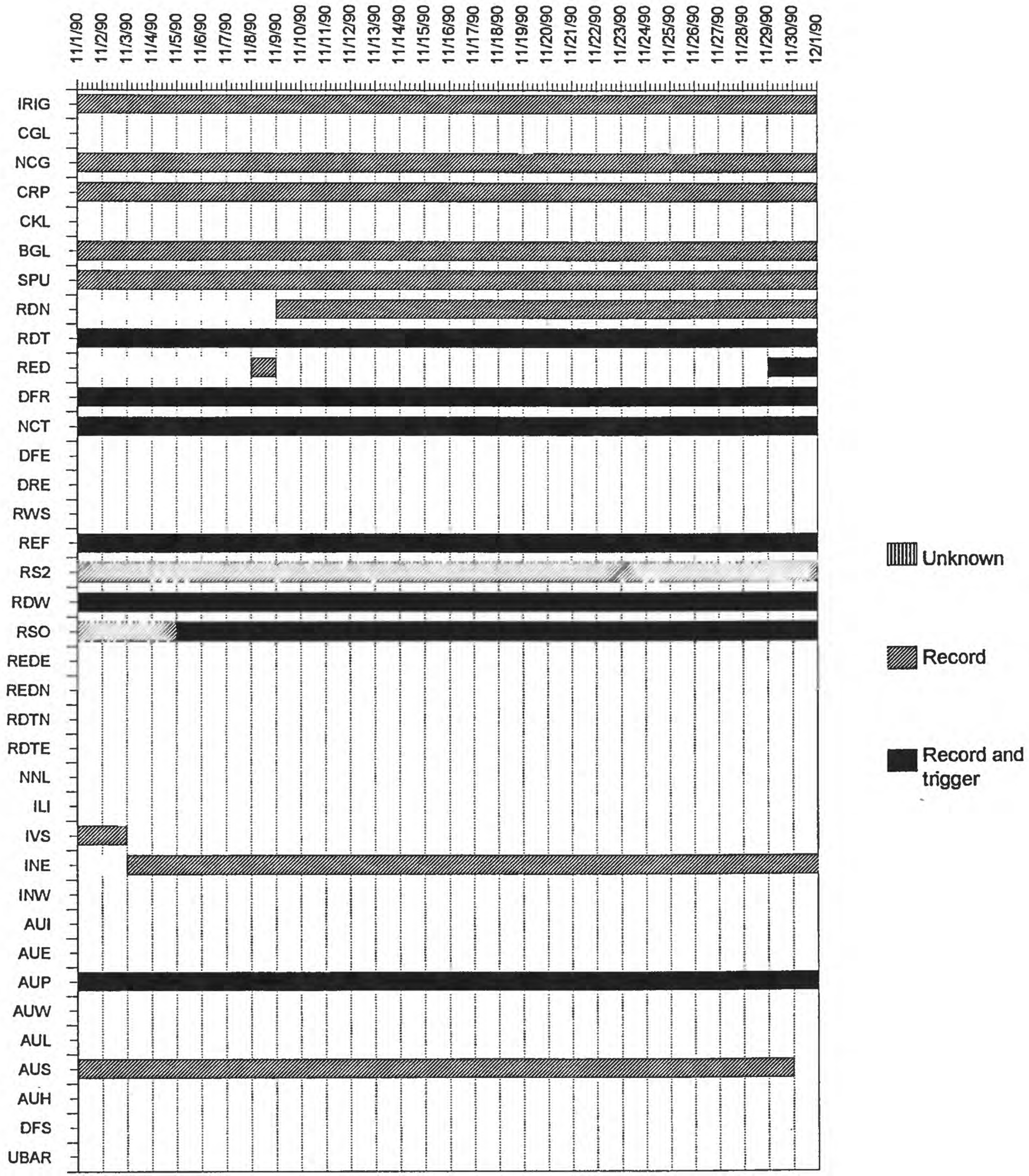
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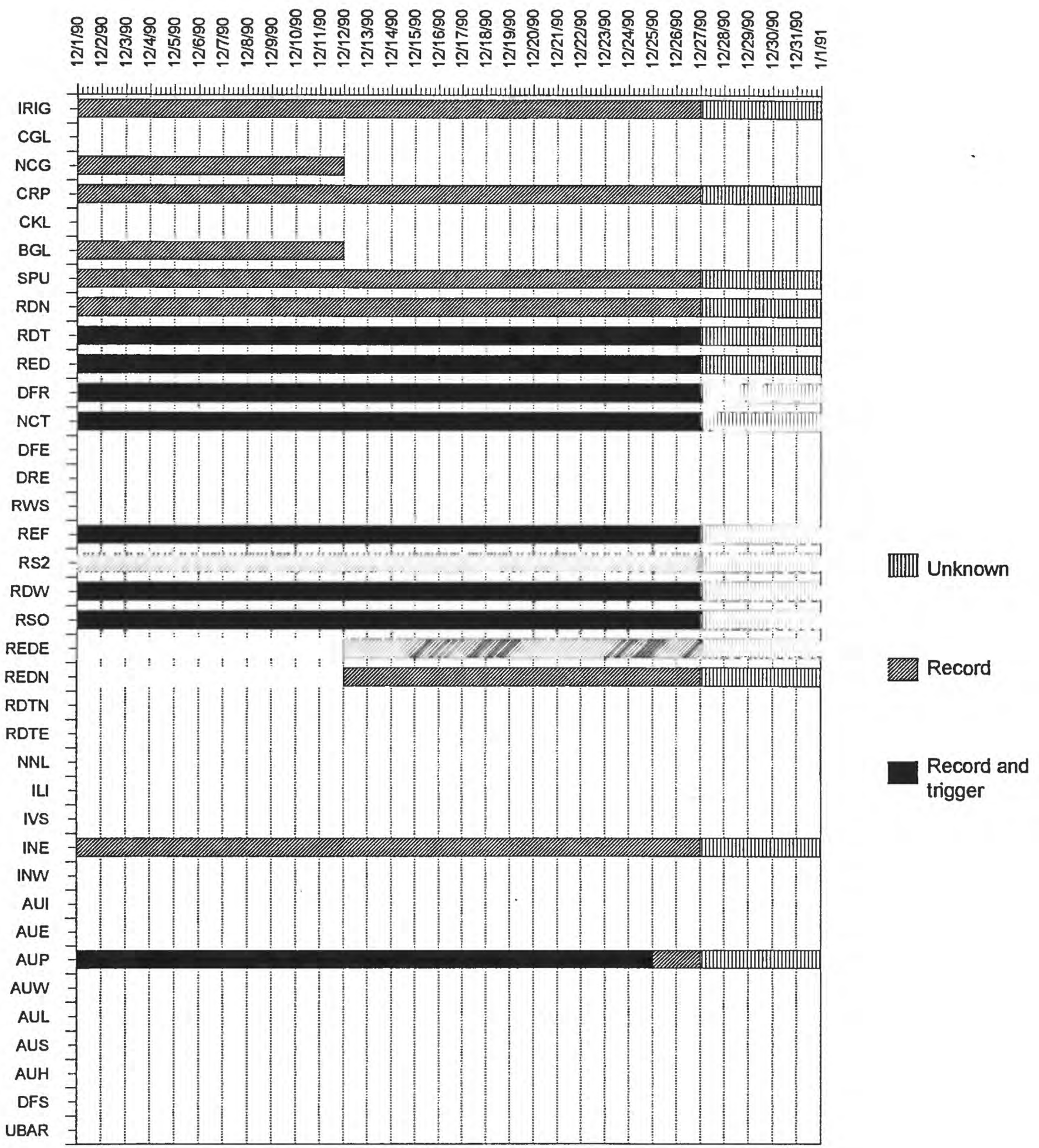
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APPENDIX C

Response curves for stations monitored by the PC/AT seismic acquisition system from December, 1989 through December, 1990. Calibration data is not available for stations CGL, REDN, REDE, and NNL during the report period. No calibration data is available for station RED between August 30 and December 21, 1990. Prior to August 30, 1990, station RED used a monitron VCO, so calculation of its response curve uses separate parameters. All other stations use the A1VCO (Rogers and others, 1980).

Station Response Curves

| Frequency | CRP | NCG | CGL | SPU | BGL | CKL | RDT | DFR |
|---|---|---|---|---|---|---|---|---|
| 0.012589 | 4.655144 | 9.879016 | no | 20.453144 | 5.266 | 5.560896 | 7.983256 | 9.078584 |
| 0.015849 | 12.384398 | 26.281822 | calibration | 54.412898 | 14.0095 | 14.794032 | 21.238402 | 24.152378 |
| 0.019953 | 29.40626 | 62.40514 | available | 129.20126 | 33.265 | 35.12784 | 50.42974 | 57.34886 |
| 0.025119 | 98.60799 | 209.26311 | | 433.25049 | 111.5475 | 117.79416 | 169.10601 | 192.30789 |
| 0.031623 | 344.318 | 730.702 | | 1512.818 | 389.5 | 411.312 | 590.482 | 671.498 |
| 0.039811 | 761.632322 | 1616.31475 | | 3346.3574 | 861.575025 | 909.823226 | 1306.14774 | 1485.35534 |
| 0.050119 | 1837.04042 | 3898.51565 | | 8071.3405 | 2078.10003 | 2194.47363 | 3150.39964 | 3582.64444 |
| 0.063096 | 5322.7848 | 11295.8646 | | 23386.5341 | 6021.24978 | 6358.43976 | 9128.21466 | 10380.6346 |
| 0.079433 | 13071.0453 | 27739.0056 | | 57429.7962 | 14786.2503 | 15614.2803 | 22415.9555 | 25491.4955 |
| 0.100000 | 31720.1311 | 67315.5723 | | 139367.635 | 35882.5012 | 37891.9213 | 54397.8719 | 61861.4321 |
| 0.125893 | 72633.8622 | 154141.545 | | 319128.87 | 82165.0025 | 86766.2426 | 124562.144 | 141652.464 |
| 0.158489 | 155046.974 | 329036.339 | | 681224.489 | 175392.505 | 185214.485 | 265895.037 | 302376.678 |
| 0.199526 | 329621.5 | 699513.5 | | 1448246.5 | 372875 | 393756 | 565278.5 | 642836.5 |
| 0.251189 | 698558.9 | 1482462.1 | | 3069233.9 | 790225 | 834477.6 | 1197981.1 | 1362347.9 |
| 0.316228 | 1418157 | 3009573 | | 6230907 | 1604250 | 1694088 | 2432043 | 2765727 |
| 0.398107 | 2905045 | 6165005 | | 12763795 | 3286250 | 3470280 | 4981955 | 5665495 |
| 0.501187 | 5874843 | 12467427 | | 25812093 | 6645750 | 7017912 | 10074957 | 11457273 |
| 0.630957 | 11652004 | 24727556 | | 51195004 | 13181000 | 13919136 | 19982396 | 22724044 |
| 0.794328 | 21345948 | 45299772 | | 93786948 | 24147000 | 25499232 | 36606852 | 41629428 |
| 1.000000 | 35751170 | 75870130 | | 157078670 | 40442500 | 42707280 | 61310830 | 69722870 |
| 1.258925 | 53619020 | 113788780 | | 235584020 | 60655000 | 64051680 | 91952980 | 104569220 |
| 1.584893 | 73480290 | 155937810 | | 322847790 | 83122500 | 87777360 | 126013710 | 143303190 |
| 1.995262 | 95757090 | 203213010 | | 420724590 | 108322500 | 114388560 | 164216910 | 186747990 |
| 2.511886 | 121987580 | 258878620 | | 535972580 | 137995000 | 145722720 | 209200420 | 237903380 |
| 3.162278 | 154065730 | 326953970 | | 676913230 | 174282500 | 184042320 | 264212270 | 300463030 |
| 3.981072 | 193993800 | 411688200 | | 852343800 | 219450000 | 231739200 | 332686200 | 378331800 |
| 5.011872 | 231453300 | 491183700 | | 1016928300 | 261825000 | 276487200 | 396926700 | 451386300 |
| 6.309573 | 284979500 | 604775500 | | 1252104500 | 322375000 | 340428000 | 488720500 | 555774500 |
| 7.943282 | 347787700 | 738065300 | | 1528062700 | 393425000 | 415456800 | 596432300 | 678264700 |
| 10.000000 | 414419200 | 879468800 | | 1820819200 | 468800000 | 495052800 | 710700800 | 808211200 |
| 12.589254 | 475127900 | 1008303100 | | 2087552900 | 537475000 | 567573600 | 814812100 | 926606900 |
| 15.848932 | 548455700 | 1163917300 | | 2409730700 | 620425000 | 655168800 | 940564300 | 1069612700 |
| 19.952623 | 535372500 | 1136152500 | | 2352247500 | 605625000 | 639540000 | 918127500 | 1044097500 |
| 25.118864 | 551881200 | 1171186800 | | 2424781200 | 624300000 | 659260800 | 946438800 | 1076293200 |
| 31.622777 | 422994000 | 897666000 | | 1858494000 | 478500000 | 505296000 | 725406000 | 824934000 |
| 39.810717 | 386860500 | 820984500 | | 1699735500 | 437625000 | 462132000 | 663439500 | 754465500 |
| 50.118723 | 305201000 | 647689000 | | 1340951000 | 345250000 | 364584000 | 523399000 | 595211000 |
| 63.095734 | 230790300 | 489776700 | | 1014015300 | 261075000 | 275695200 | 395789700 | 450093300 |
| 79.432823 | 97295250 | 206477250 | | 427482750 | 110062500 | 116226000 | 166854750 | 189747750 |
| 100.000000 | 74017320 | 157077480 | | 325207320 | 83730000 | 88418880 | 126934680 | 144350520 |

Station Response Curves

| NCT | RDN * | RDN + | REF | RSO | RWS | RDW | RS2 | RDTN |
|---|---|---|---|---|---|---|---|---|
| 4.865784 | 4.52876 | 5.076424 | 4.613016 | 5.16068 | 3.854712 | 4.697272 | 4.549824 | 2.295976 |
| 12.944778 | 12.04817 | 13.505158 | 12.272322 | 13.72931 | 10.254954 | 12.496474 | 12.104208 | 6.108142 |
| 30.73686 | 28.6079 | 32.06746 | 29.14014 | 32.5997 | 24.34998 | 29.67238 | 28.74096 | 14.50354 |
| 103.06989 | 95.93085 | 107.53179 | 97.71561 | 109.31655 | 81.65277 | 99.50037 | 96.37704 | 48.63471 |
| 359.898 | 334.97 | 375.478 | 341.202 | 381.71 | 285.114 | 347.434 | 336.528 | 169.822 |
| 796.095323 | 740.954522 | 830.558324 | 754.739722 | 844.343525 | 630.672918 | 768.524922 | 744.400822 | 375.646711 |
| 1920.16442 | 1787.16602 | 2003.28842 | 1820.41562 | 2036.53802 | 1521.16922 | 1853.66522 | 1795.47842 | 906.051611 |
| 5563.63479 | 5178.27481 | 5804.48478 | 5274.6148 | 5900.82478 | 4407.55484 | 5370.9548 | 5202.35981 | 2625.2649 |
| 13662.4953 | 12716.1753 | 14253.9453 | 12952.7553 | 14490.5253 | 10823.5352 | 13189.3353 | 12775.3203 | 6446.80513 |
| 33155.4311 | 30858.9511 | 34590.7312 | 31433.0711 | 35164.8512 | 26265.9909 | 32007.1911 | 31002.4811 | 15644.7705 |
| 75920.4623 | 70661.9021 | 79207.0624 | 71976.5421 | 80521.7024 | 60144.7818 | 73291.1822 | 70990.5621 | 35823.9411 |
| 162062.675 | 150837.554 | 169078.375 | 153643.834 | 171884.655 | 128387.314 | 156450.114 | 151539.124 | 76471.1321 |
| 344536.5 | 320672.5 | 359451.5 | 326638.5 | 365417.5 | 272944.5 | 332604.5 | 322164 | 162573.5 |
| 730167.9 | 679593.5 | 761776.9 | 692237.1 | 774420.5 | 578444.7 | 704880.7 | 682754.4 | 344538.1 |
| 1482327 | 1379655 | 1546497 | 1405323 | 1572165 | 1174311 | 1430991 | 1386072 | 699453 |
| 3036495 | 2826175 | 3167945 | 2878755 | 3220525 | 2405535 | 2931335 | 2839320 | 1432805 |
| 6140673 | 5715345 | 6406503 | 5821677 | 6512835 | 4864689 | 5928009 | 5741928 | 2897547 |
| 12179244 | 11335660 | 12706484 | 11546556 | 12917380 | 9648492 | 11757452 | 11388384 | 5746916 |
| 22311828 | 20766420 | 23277708 | 21152772 | 23664060 | 17675604 | 21539124 | 20863008 | 10528092 |
| 37368870 | 34780550 | 38986570 | 35427630 | 39633650 | 29603910 | 36074710 | 34942320 | 17632930 |
| 56045220 | 52163300 | 58471420 | 53133780 | 59441900 | 44399460 | 54104260 | 52405920 | 26445580 |
| 76805190 | 71485350 | 80130090 | 72815310 | 81460050 | 60845670 | 74145270 | 71817840 | 36241410 |
| 100089990 | 93157350 | 104422890 | 94890510 | 106156050 | 79292070 | 96623670 | 93590640 | 47228610 |
| 127507380 | 118675700 | 133027180 | 120883620 | 135235100 | 101012340 | 123091540 | 119227680 | 60165820 |
| 161037030 | 149882950 | 168008330 | 152671470 | 170796850 | 127574790 | 155459990 | 150580080 | 75987170 |
| 202771800 | 188727000 | 211549800 | 192238200 | 215061000 | 160637400 | 195749400 | 189604800 | 95680200 |
| 241926300 | 225169500 | 252399300 | 229358700 | 256588500 | 191655900 | 233547900 | 226216800 | 114155700 |
| 297874500 | 277242500 | 310769500 | 282400500 | 315927500 | 235978500 | 287558500 | 278532000 | 140555500 |
| 363524700 | 338345500 | 379261700 | 344640300 | 385556500 | 287987100 | 350935100 | 339919200 | 171533300 |
| 433171200 | 403168000 | 451923200 | 410668800 | 459424000 | 343161600 | 418169600 | 405043200 | 204396800 |
| 496626900 | 462228500 | 518125900 | 470828100 | 526725500 | 393431700 | 479427700 | 464378400 | 234339100 |
| 573272700 | 533565500 | 598089700 | 543492300 | 608016500 | 454151100 | 553419100 | 536047200 | 270505300 |
| 559597500 | 520837500 | 583822500 | 530527500 | 593512500 | 443317500 | 540217500 | 523260000 | 264052500 |
| 576853200 | 536898000 | 601825200 | 546886800 | 611814000 | 456987600 | 556875600 | 539395200 | 272194800 |
| 442134000 | 411510000 | 461274000 | 419166000 | 468930000 | 350262000 | 426822000 | 413424000 | 208626000 |
| 404365500 | 376357500 | 421870500 | 383359500 | 428872500 | 320341500 | 390361500 | 378108000 | 190804500 |
| 319011000 | 296915000 | 332821000 | 302439000 | 338345000 | 252723000 | 307963000 | 298296000 | 150529000 |
| 241233300 | 224524500 | 251676300 | 228701700 | 255853500 | 191106900 | 232878900 | 225568800 | 113828700 |
| 101697750 | 94653750 | 106100250 | 96414750 | 107861250 | 80565750 | 98175750 | 95094000 | 47987250 |
| 77366520 | 72007800 | 80715720 | 73347480 | 82055400 | 61290360 | 74687160 | 72342720 | 36506280 |

* Before 2/15/90

\+ After 8/30/90

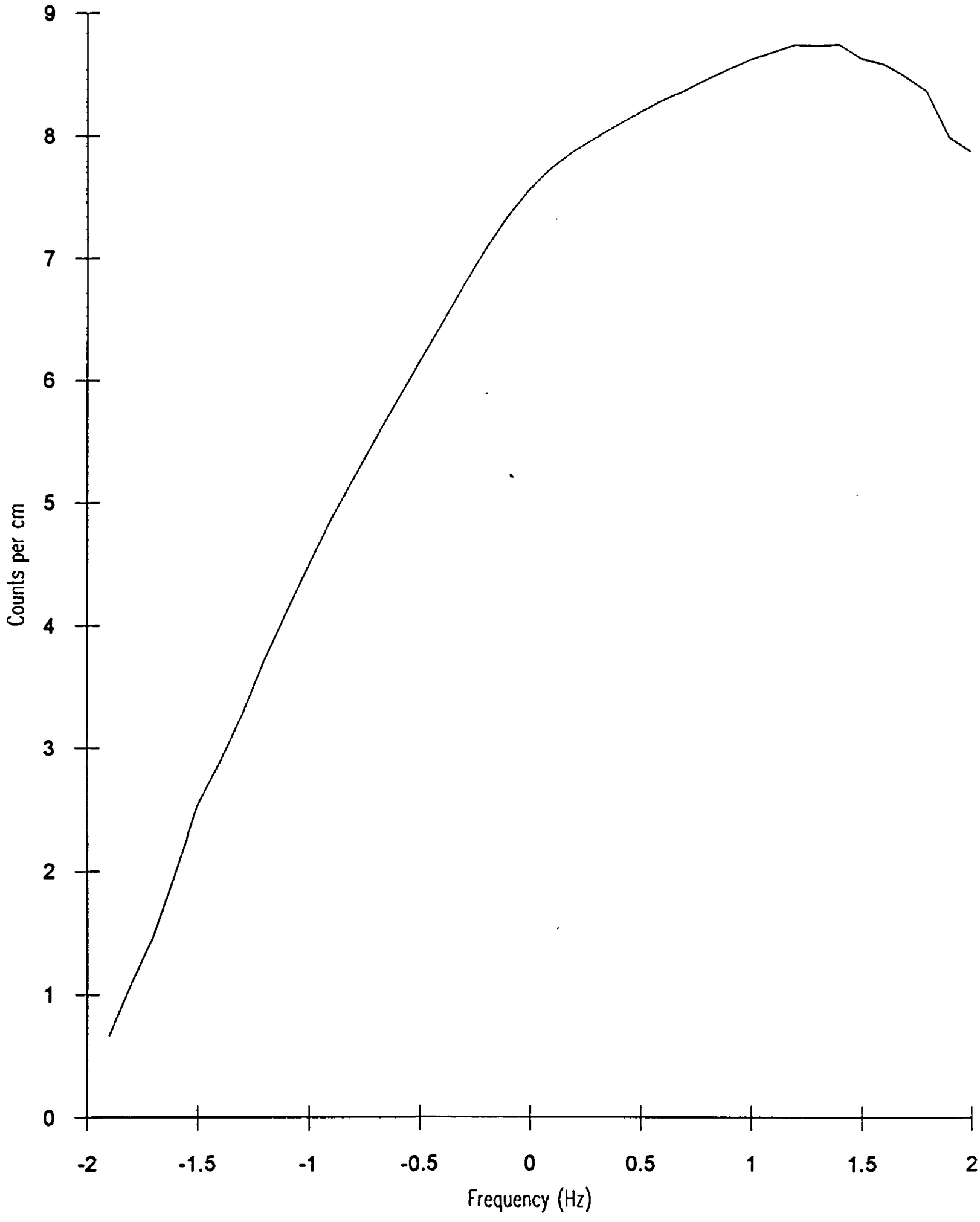
## Station Response Curves

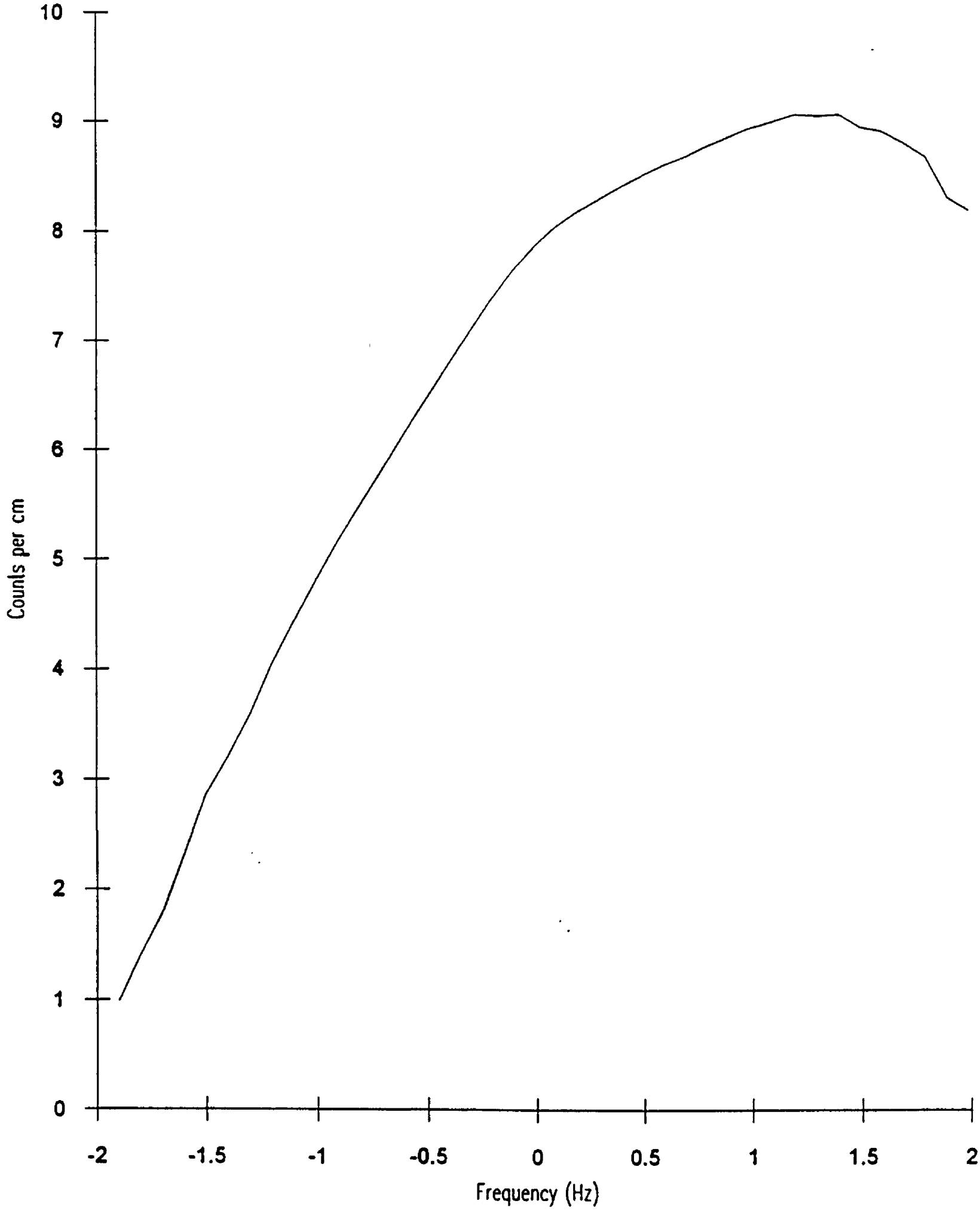
| RDTE | RED # | REDN | REDE | NNL |
|---|---|---|---|---|
| 2.274912 | no | no | no | no |
| 6.052104 | calibration | calibration | calibration | calibration |
| 14.37048 | available | available | available | available |
| 48.18852 | | | | |
| 168.264 | | | | |
| 372.200411 | | | | |
| 897.739211 | | | | |
| 2601.1799 | | | | |
| 6387.66013 | | | | |
| 15501.2405 | | | | |
| 35495.2811 | | | | |
| 75769.5621 | | | | |
| 161082 | | | | |
| 341377.2 | | | | |
| 693036 | | | | |
| 1419660 | | | | |
| 2870964 | | | | |
| 5694192 | | | | |
| 10431504 | | | | |
| 17471160 | | | | |
| 26202960 | | | | |
| 35908920 | | | | |
| 46795320 | | | | |
| 59613840 | | | | |
| 75290040 | | | | |
| 94802400 | | | | |
| 113108400 | | | | |
| 139266000 | | | | |
| 169959600 | | | | |
| 202521600 | | | | |
| 232189200 | | | | |
| 268023600 | | | | |
| 261630000 | | | | |
| 269697600 | | | | |
| 206712000 | | | | |
| 189054000 | | | | |
| 149148000 | | | | |
| 112784400 | | | | |
| 47547000 | | | | |
| 36171360 | | | | |

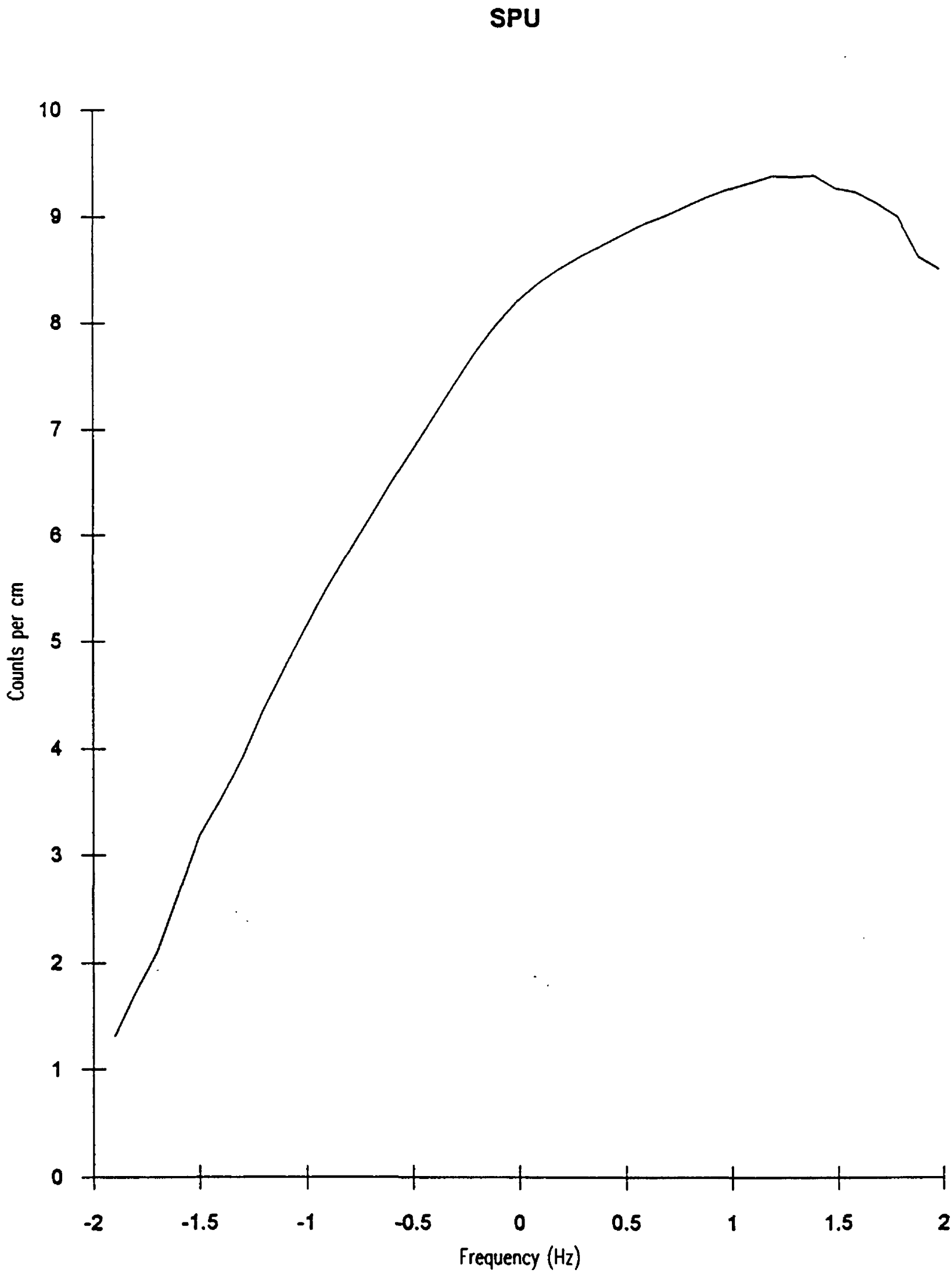
Monitron VCO

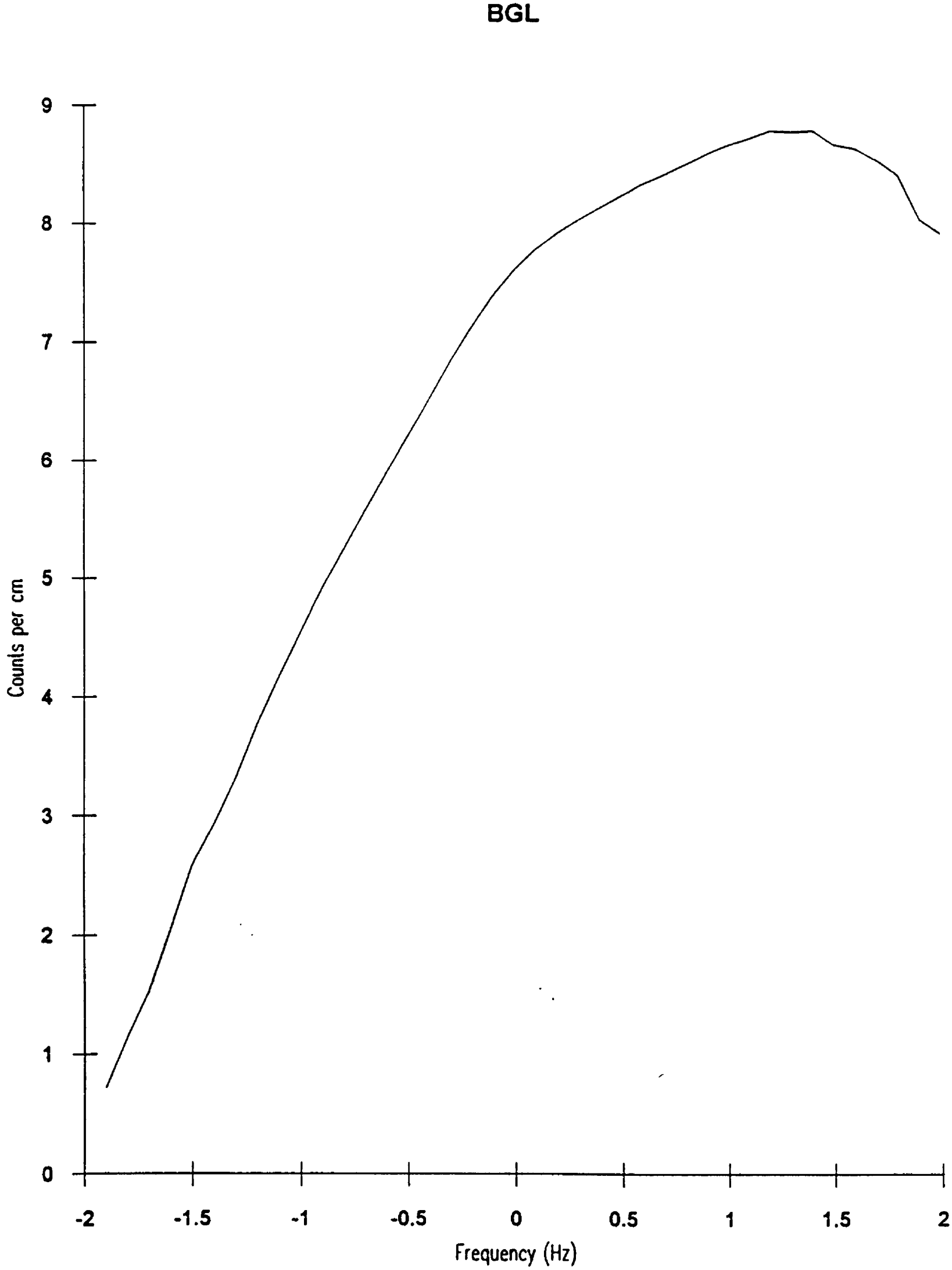
| Frequency | RED ## | DRE |
|---|---|---|
| 0.1 | 4606 | no |
| 0.2 | 36106 | calibration |
| 0.4 | 182915 | available |
| 0.5 | 479641 | |
| 0.8 | 1328618 | |
| 1.0 | 2428016 | |
| 1.7 | 5847094 | |
| 2.0 | 7517646 | |
| 2.5 | 9981755 | |
| 3.3 | 13942052 | |
| 5.0 | 20309967 | |
| 10 | 30515013 | |
| 15 | 34959133 | |
| 20 | 34672125 | |
| 30 | 26028727 | |
| 40 | 15837535 | |
| 50 | 2503975 | |

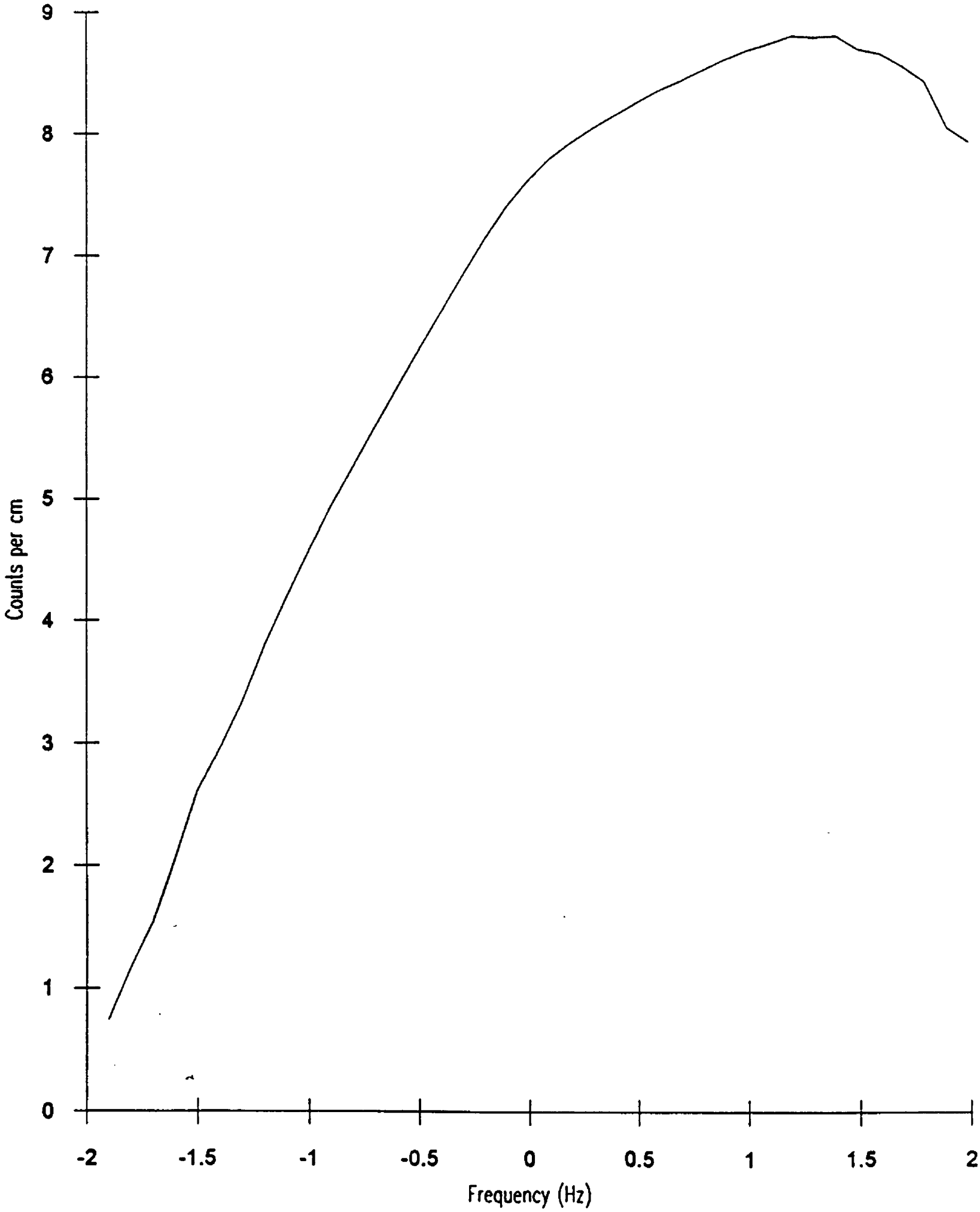
# After 8/30/90, maintained by U.S. Geological Survey
## Before 8/30/90, maintained by University of Alaska

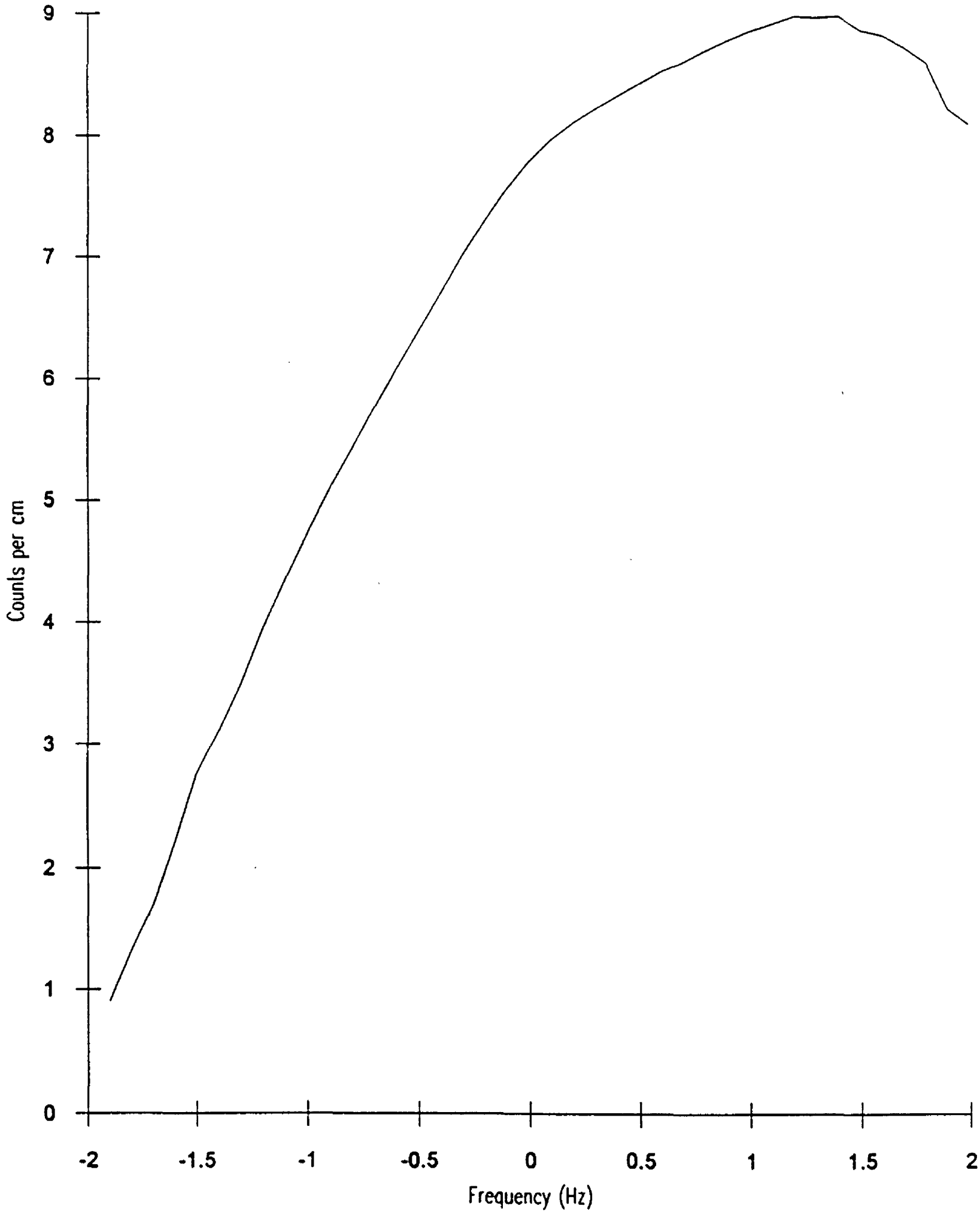

CRP
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

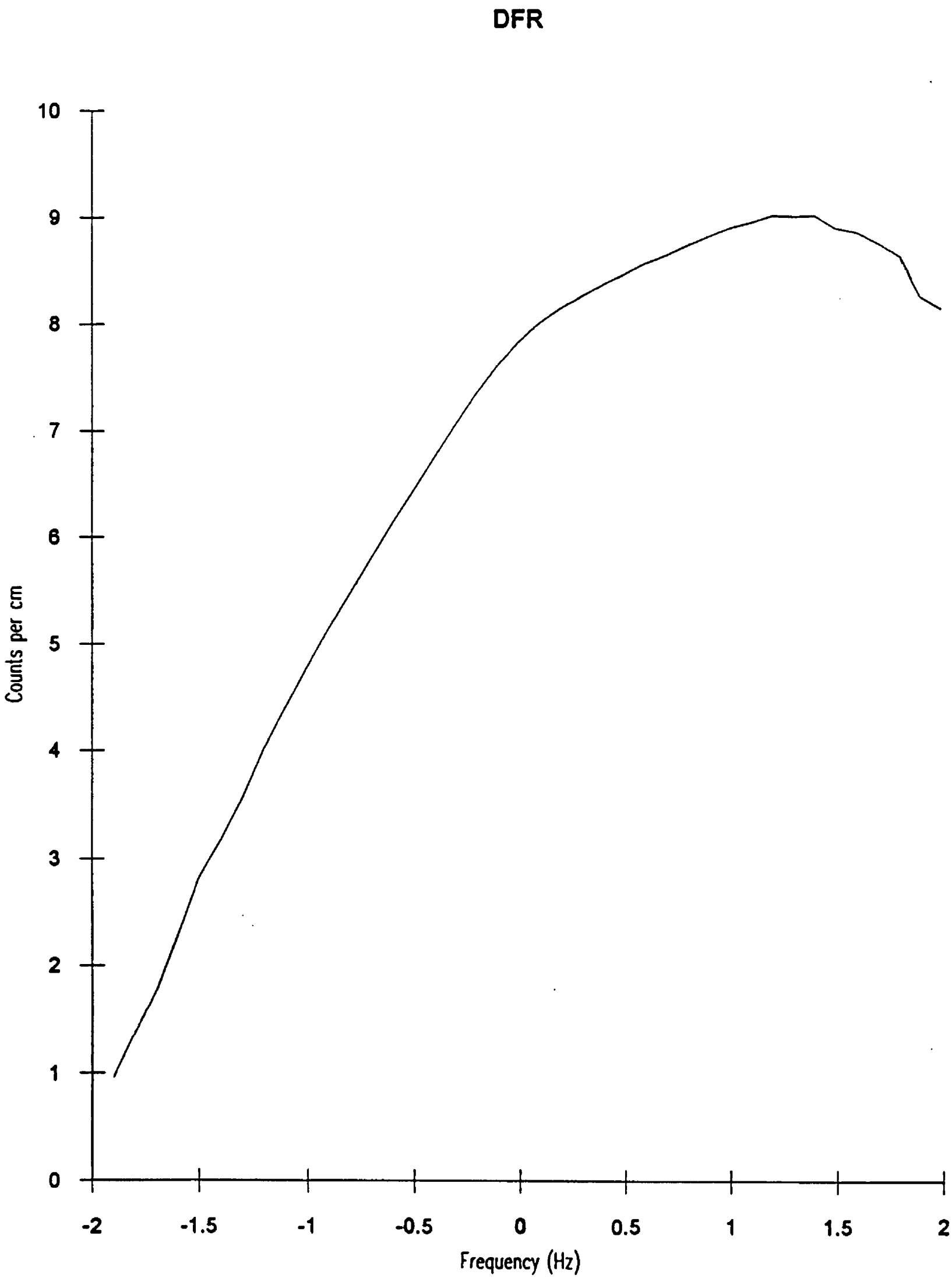

NCG
10
9
8
7
6
5
4
3
2
1
0
Counts per cm
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

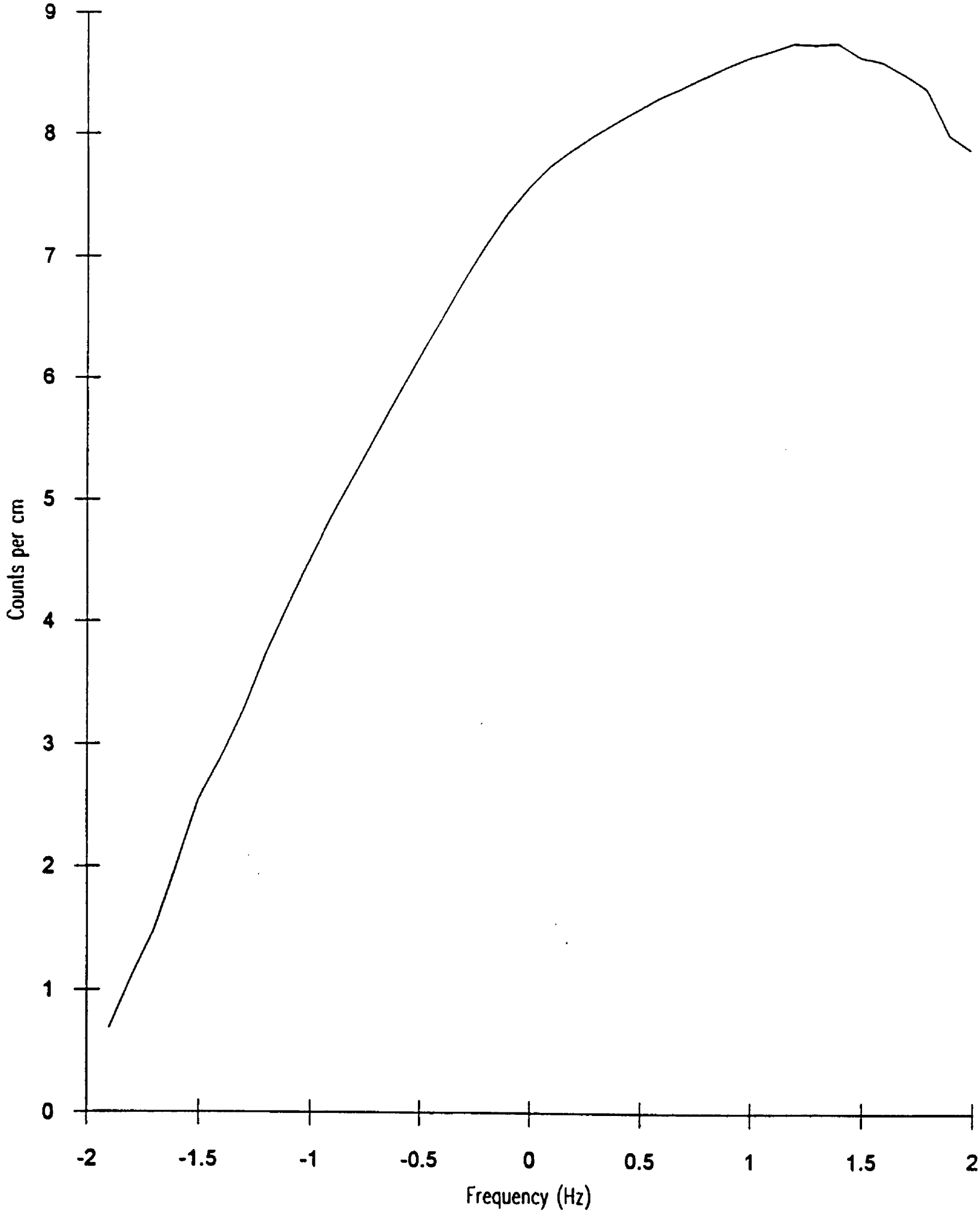

SPU
10
9
8
7
6
5
4
3
2
1
0
Counts per cm
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

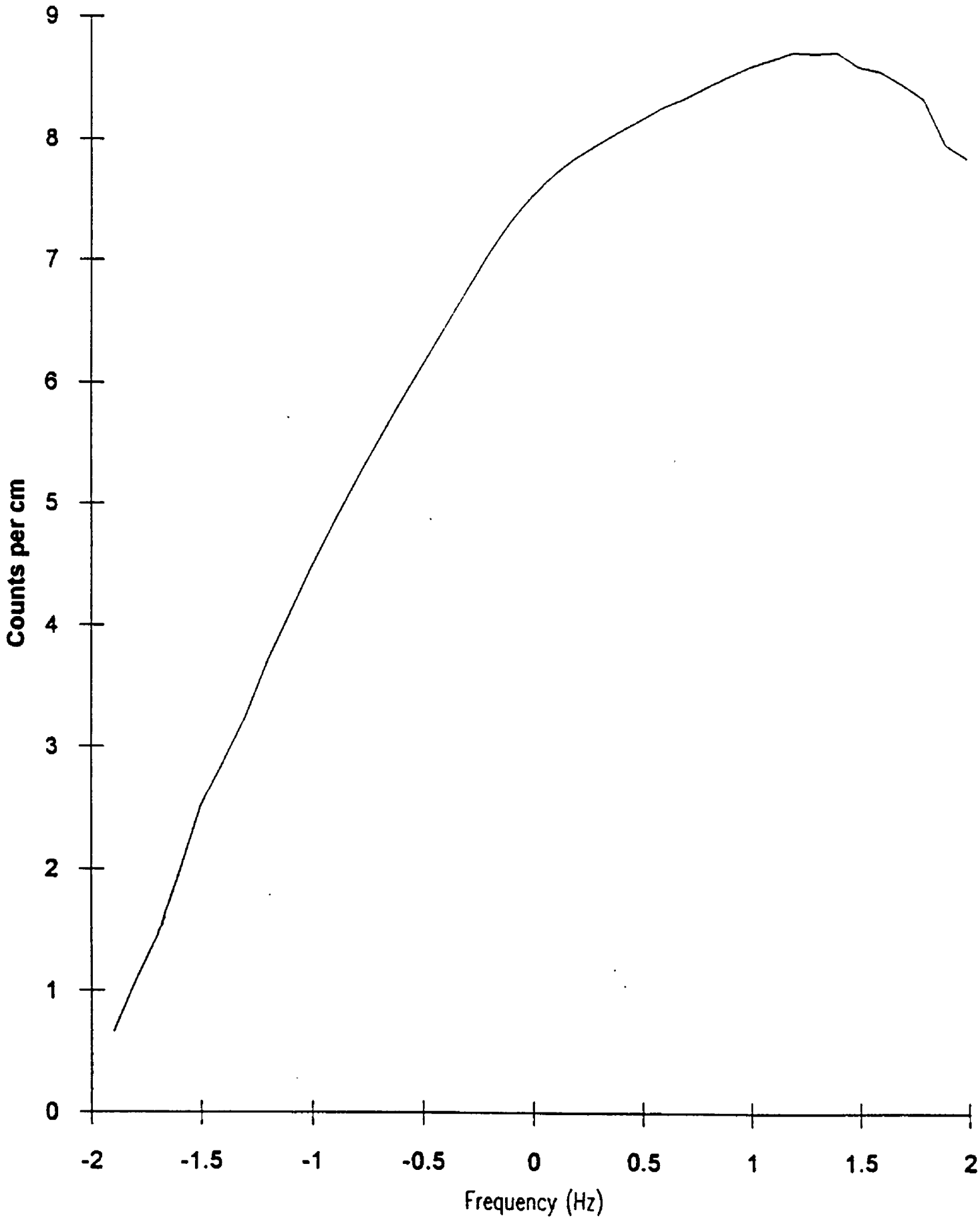

BGL
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


CKL
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

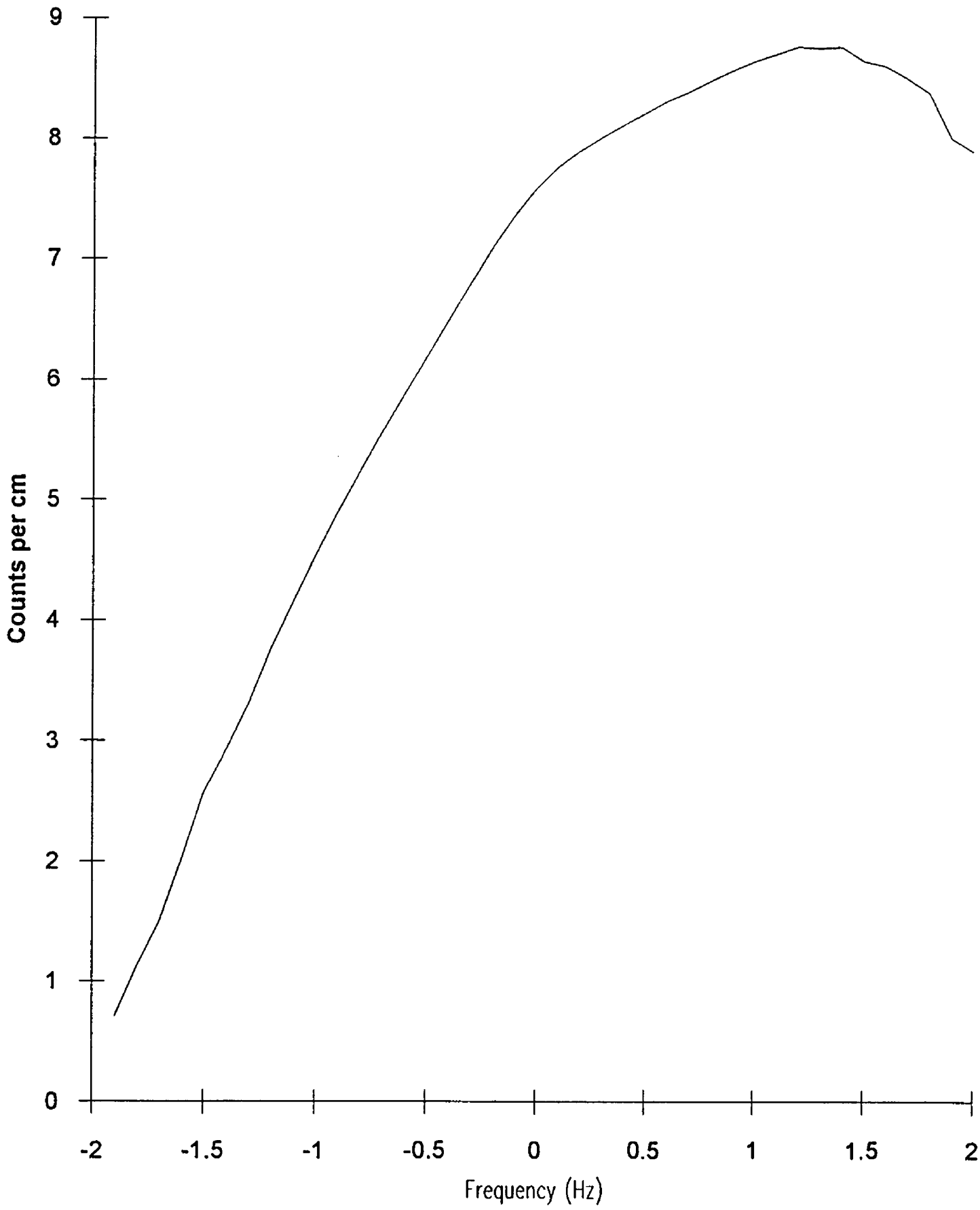

RDT
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


DFR
10
9
8
7
6
5
4
3
2
1
0
Counts per cm
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

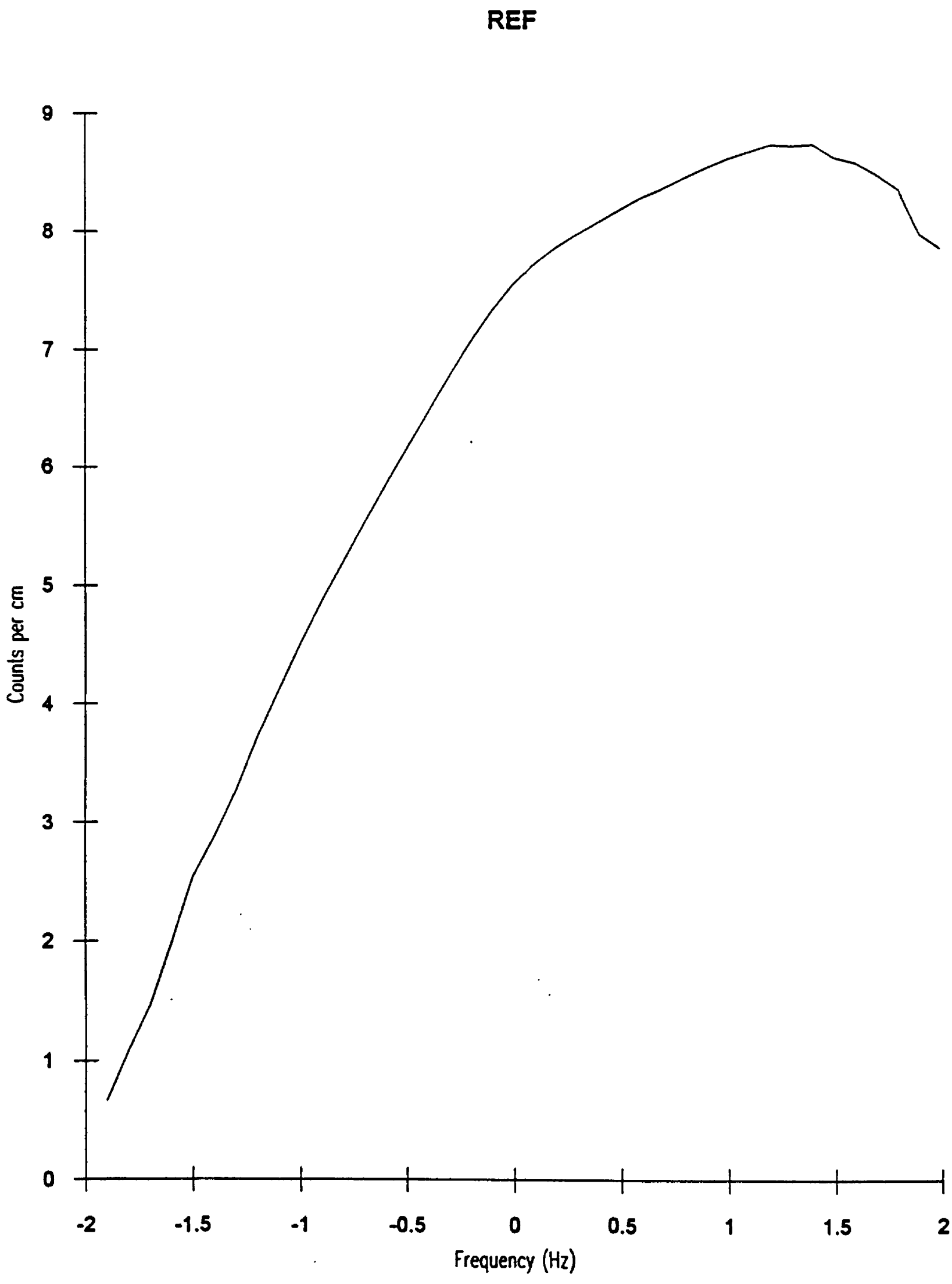

NCT
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

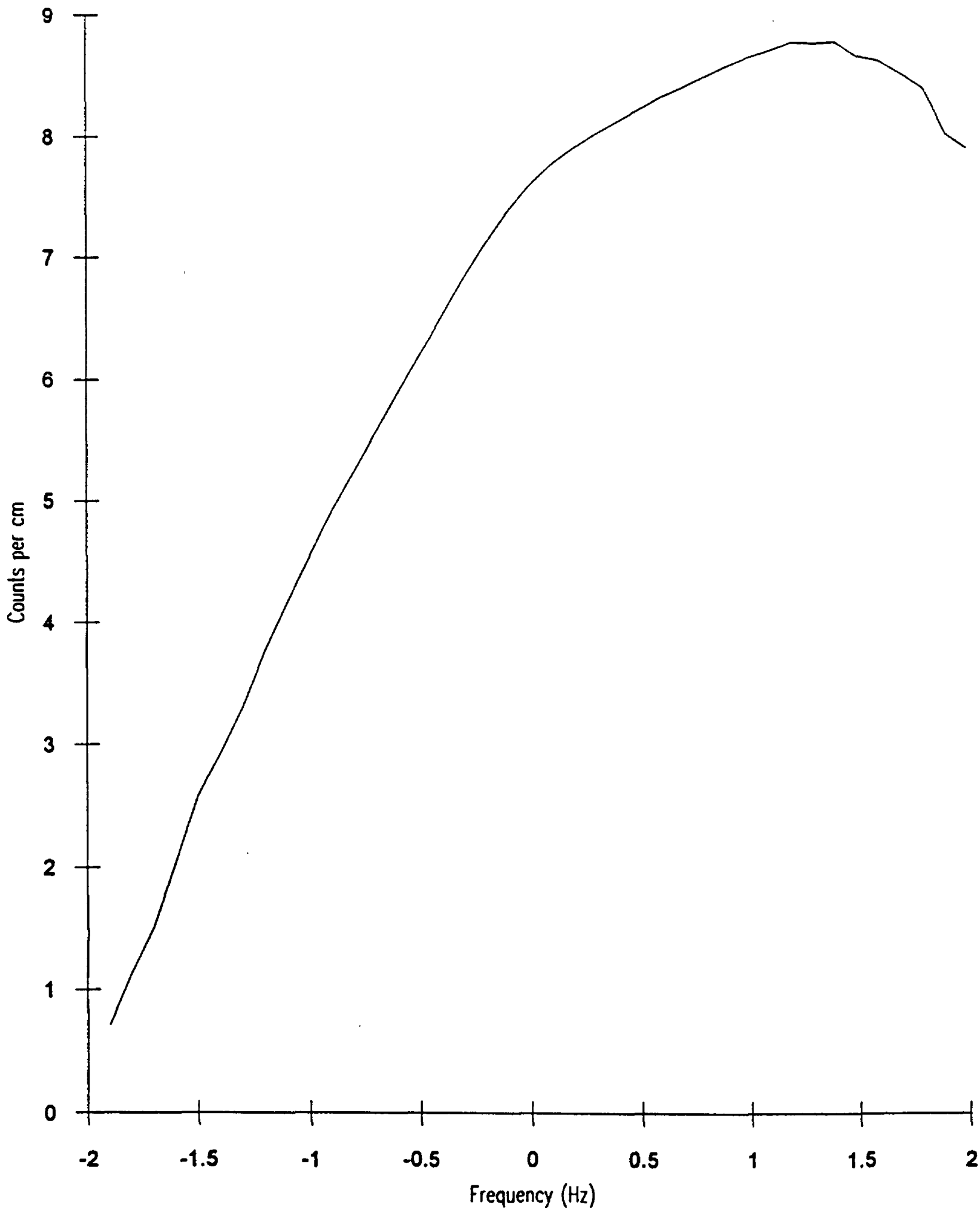


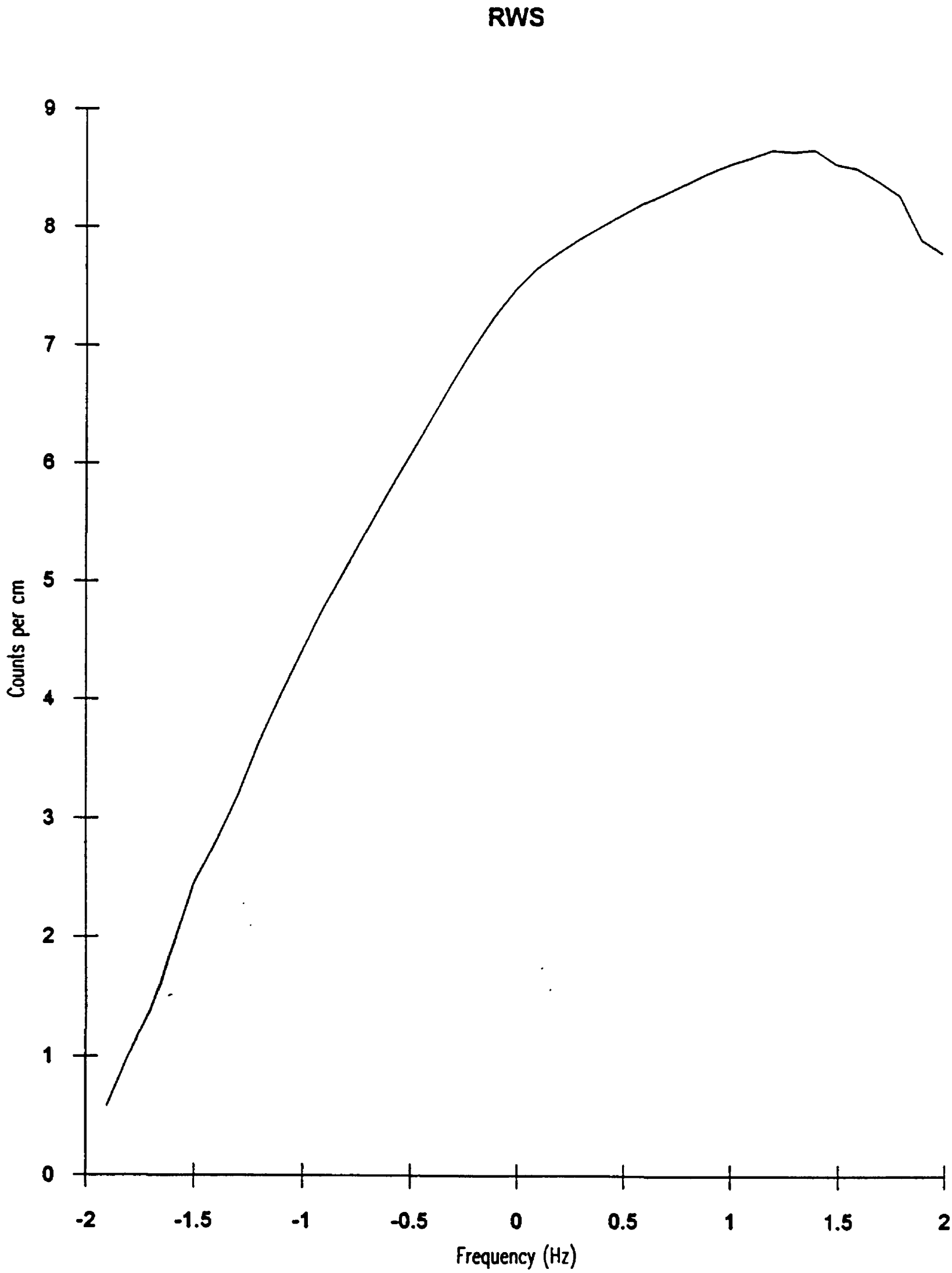

Before February 15, 1990

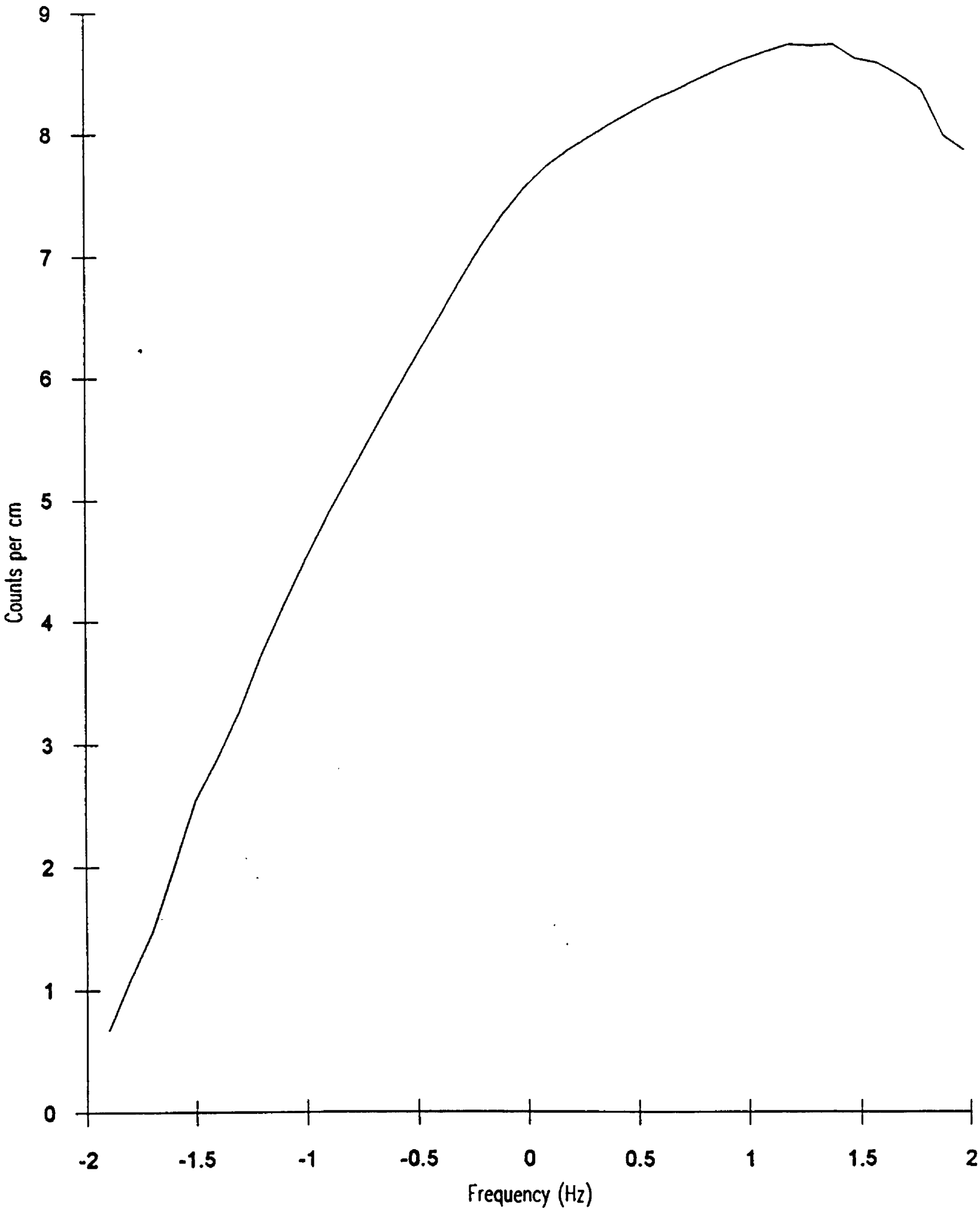


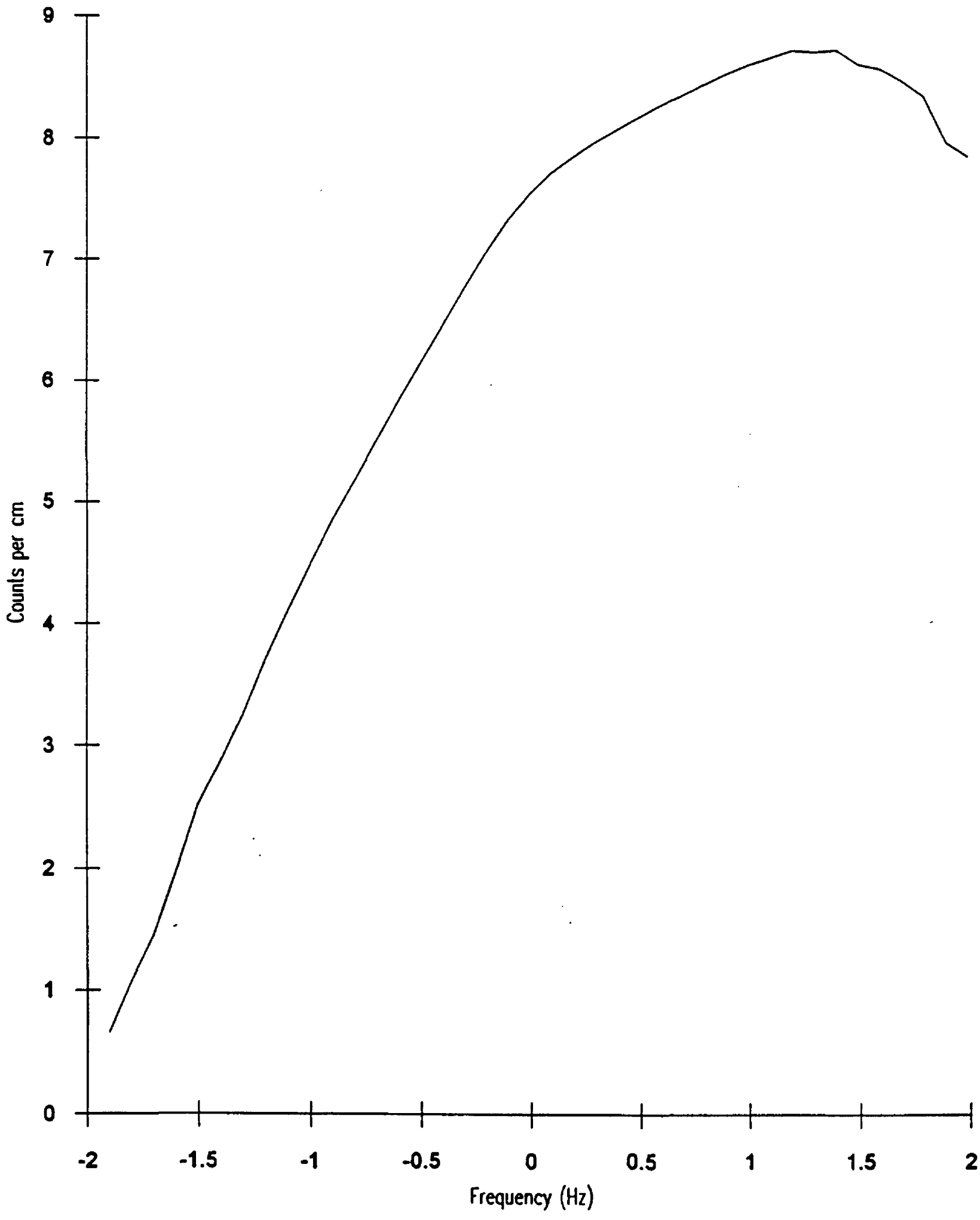

After August 30, 1990

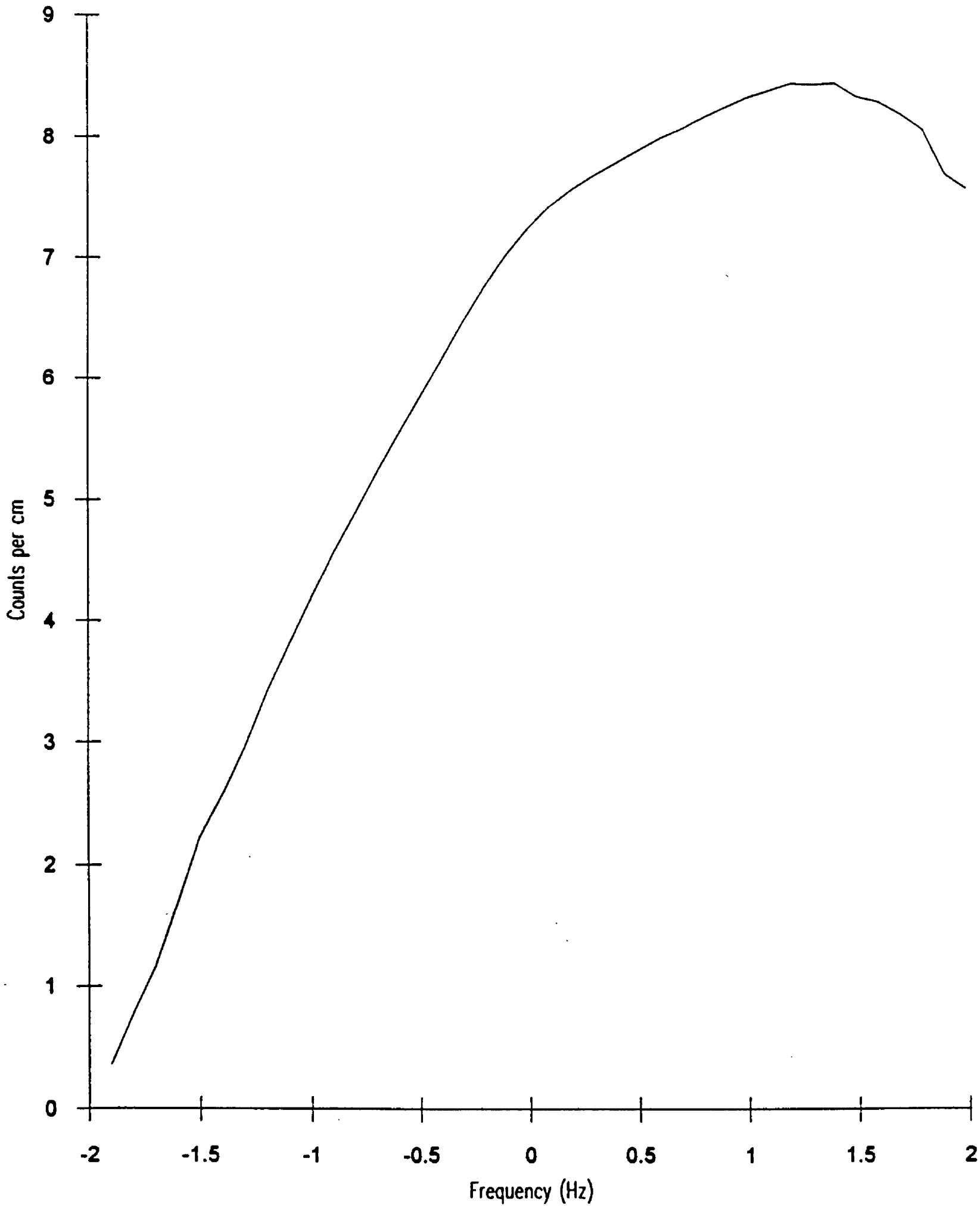

REF
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

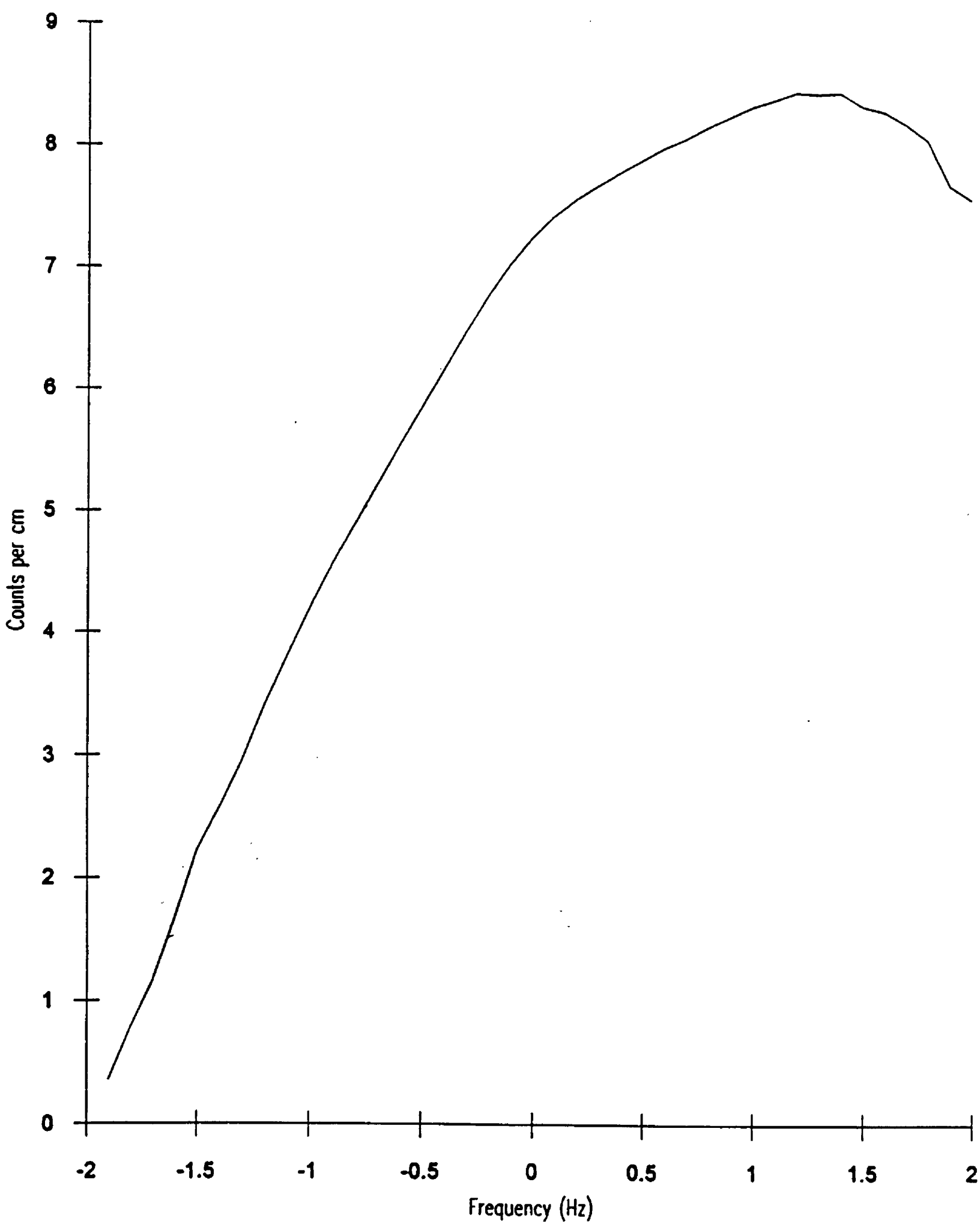

RSO
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)

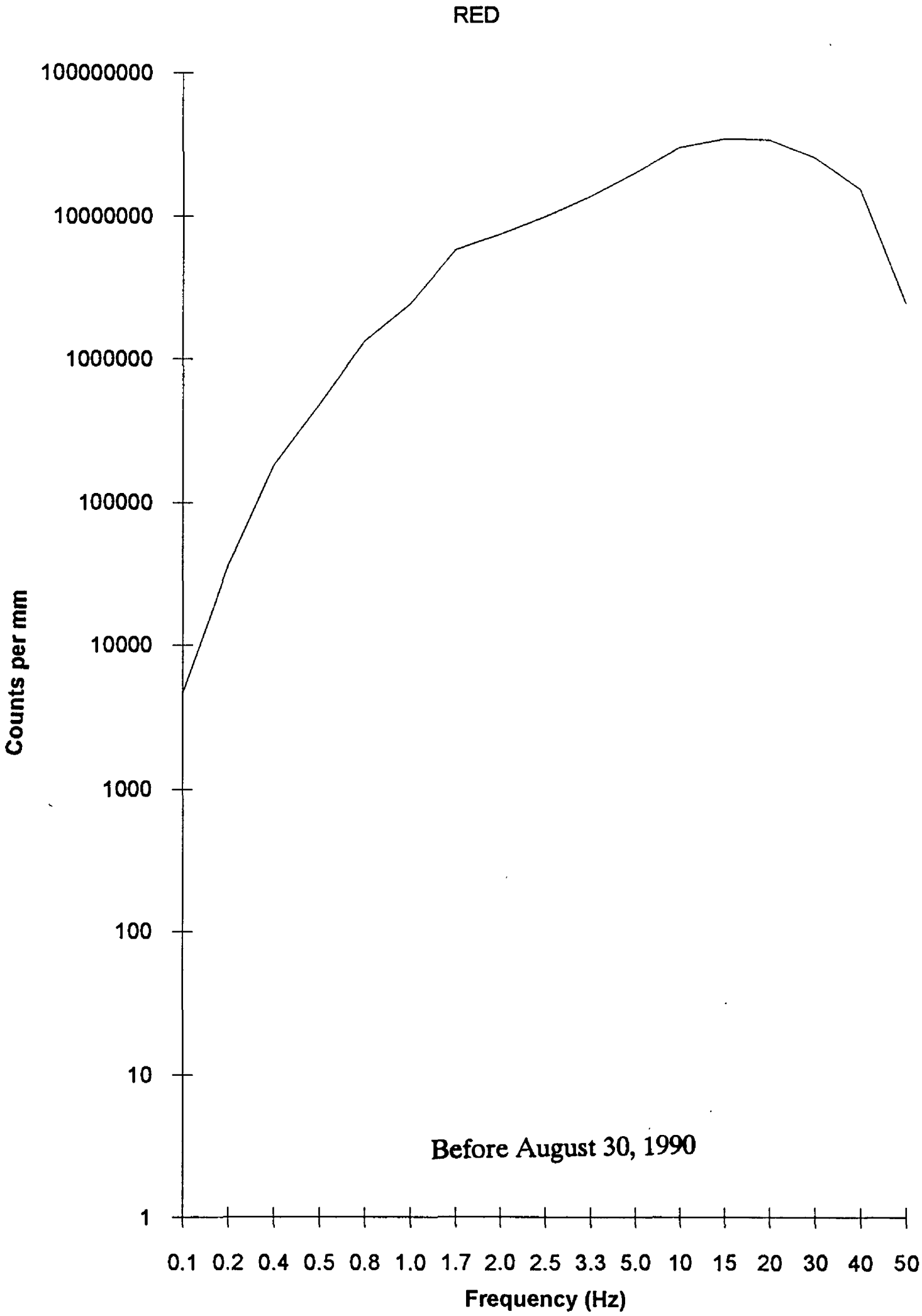

RWS
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


RDW
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


RS2
9
8
7
6
5
4
3
2
1
0
Counts per cm
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


RDTN
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


RDTE
Counts per cm
9
8
7
6
5
4
3
2
1
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Frequency (Hz)


RED
100000000
10000000
1000000
100000
10000
1000
100
10
1
Counts per mm
Before August 30, 1990
0.1 0.2 0.4 0.5 0.8 1.0 1.7 2.0 2.5 3.3 5.0 10 15 20 30 40 50
Frequency (Hz)