Orbiting Meteoroid and Debris Counting Experiment

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Abstract

The Orbiting Meteoroid and Debris Counting Experiment (OMDC) flew for approximately 90 days in a highly elliptical Earth orbit onboard the Clementine Interstage Adapter (ISA) Spacecraft. This experiment obtained data on the impact flux of natural micrometeoroids, and, it provided limited information on the population of small mass man-made debris as a function of altitude in near Earth space. The flight of the OMDC Experiment on the ISA Spacecraft also demonstrated that the ultra lightweight, low-power, particle impact detector system that was used is a viable system for flights on future spacecraft to monitor the population of small mass man-made debris particles and to map the cosmic dust environment encountered on interplanetary missions. An overview of the ISA Spacecraft mission, the approach to the OMDC Experiment and the data obtained by the experiment are presented.

I. Introduction / Background

Orbital debris represents an inescapable hazard for all space activities. Over the past several years the U.S. and international communities have recognized this present and growing threat as a dominant space environment concern in low altitude earth orbits and a growing concern in higher altitude orbits - particularly in synchronous orbits. The U.S. Congress Office of Technology Assessment has concluded that uncontrolled growth of space operations, including operations by the private sector, could eventually result in a debris population that will inflict severe limitations on space missions.[1] Other investigative organizations, including the National Security Council and the General Accounting Office, as well as NASA and the European Space Agency, have also addressed this problem.[2-5] At issue is not just the possibility of catastrophic collisions of large debris objects with spacecraft, but also surface damage to instruments and systems on spacecraft which can result from

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impacts of very small debris particles. In fact, surface damage resulting from small particle impacts may become more of a concern in the future with the current trend to fly more and more smaller spacecraft. These small spacecraft will have a very low probability being impacted by debris large enough to inflict catastrophic damage; however, the continuous bombardment of small debris can result in surface alterations that will limit their useful lifetime on orbit.

A prerequisite to establishing the controls needed to limit future growth in the man-made debris population and to getting these controls accepted by all space faring nations is the development of adequate data bases and models to define the sources of debris and the populations, sizes and orbits of the particles that are generated by these sources. Terrestrial measurements made by the Goldstone and Haystack ground-based radars, the GEODSS telescopes, along with data from USSPACECOM are providing adequate information on the population and orbits of debris objects that are a centimeter and larger in size near the Earth. Adequate measurements of the populations of smaller debris particles are not yet being made.

To date the LDEF experiments have provided the best indications of the small mass debris populations; however, separating the man-made debris impacts on these experiments from the natural meteoroid impacts has proven to be difficult. Also the LDEF provided data on debris only at the altitude of its near circular orbit (approximately 430 km). Prior to the Clementine mission there had been essentially no measurements that were focused on the populations of small mass debris at high altitudes and particularly near the synchronous orbits.

The Clementine ISA spacecraft, which flew in a highly elliptic orbit with a perigee altitude of approximately 127,000 km, spent most of its orbiting lifetime at altitudes above the orbits of man-made debris; thus, it provided an opportunity to obtain data on the natural meteoroid environment with no confusion introduced by man-made debris impacts. The ISA spacecraft's low perigee altitude, approximately 290 km, also allowed limited times to obtain data on the population of debris as a function of altitude. The OMDC Experiment was flown on the ISA spacecraft to take advantage of these opportunities and to establish whether or not the new detectors used in the experiment are a viable candidate for future spacecraft flights to monitor changes in man-made debris populations and to measure the natural meteoroid environments encountered during interplanetary missions.

The OMDC Experiment development, integration and post flight analysis were funded by the NASA Office of Advanced Concepts. The NASA Langley Research Center (LaRC) provided the overall management of the experiment and LaRC personnel designed and manufactured in-house all elements of the experiment hardware with the exception of the detectors. The impact detectors were developed and manufactured by faculty and students at North Carolina State University. Personnel at the Institute of Space Science and Technology generated the science requirements to supported the experiment development.

It is worthy to note that the OMDC Experiment was designed, manufactured, tested, and integrated on the ISA Spacecraft in less than 4 months and at a cost of only $200,000, and that the experiment hardware meet all Clementine Program requirements including requirements that it weigh approximately 460 grams and use less than 10 milli watts of power.

II. General Approach

The basic approach to the OMDC Experiment was to measure the impact frequencies of sub micron particles as a function of time and spatial position. It was assumed that the impacts detected at altitudes above 46,000 km, the altitude of satellites in synchronous orbits, will be the result of collisions with natural meteoroids only. Knowing the effects of the Earth's gravitational focusing of these meteoroids, it was also assumed that the natural meteoroid impact fluxes at lower altitudes can be established from flux measurements made at altitudes above 46,000 km. At altitudes below 46,000 km impacts of both natural meteoroids and man-made debris particles will be detected. The debris impact fluxes at these altitudes can be established by subtracting the calculated natural meteoroid impact flux from the combined meteoroid and debris flux measurements obtained by the OMDC Experiment.

III. MOS Detectors

The OMDC Experiment utilized improved ultra-light weight MOS (metal-oxide-silicon) impact detectors that are a derivative of the MOS detectors flown earlier in the Interplanetary Dust Experiment (IDE)[6] on the Long Duration Exposure Facility (LDEF) and on the Meteoroid Technology Satellite (MTS)[7]. The improved MOS detectors, which were rectangular 3.9 cm wide and 7.7 cm long, were manufactured from 10.2 cm diameter silicon wafers cut 0.3 mm thick. A schematic of the detector and electrical connections is illustrated in Figure 1.

The surfaces of the 10.2 cm silicon wafers were oxidized to produce a silicon dioxide layer 1.0 μm thick. The wafers were then masked to the rectangular detector shape and aluminum was vapor deposited to a thickness of 0.1μm on the silicon dioxide layer on the front. The aluminum and the silicon substrate thus formed the plates of a capacitor. The silicon dioxide layer formed the capacitor dielectric. These capacitors were charged to a nominal 43 volt bias. Impacts of particles having sufficient mass and velocity to penetrate the silicon dioxide dielectric layer will discharge the capacitor and the discharge current flow will burn the vapor deposited aluminum layer away from the region surrounding the impact site, thus allowing the capacitor to be recharged. The capacitor discharges are monitored to detect the particle penetration events. Extensive laboratory calibrations of the MOS detectors have established the impacting particle mass and velocities that are required for detection.[8] The detectors weighed approximately .5 gram each, an order of magnitude less than the similar MOS detectors that were used earlier on the LDEF IDE and on the MTS. Figure 2. shows photographs of an OMDC detector and for comparison an earlier IDE detector.

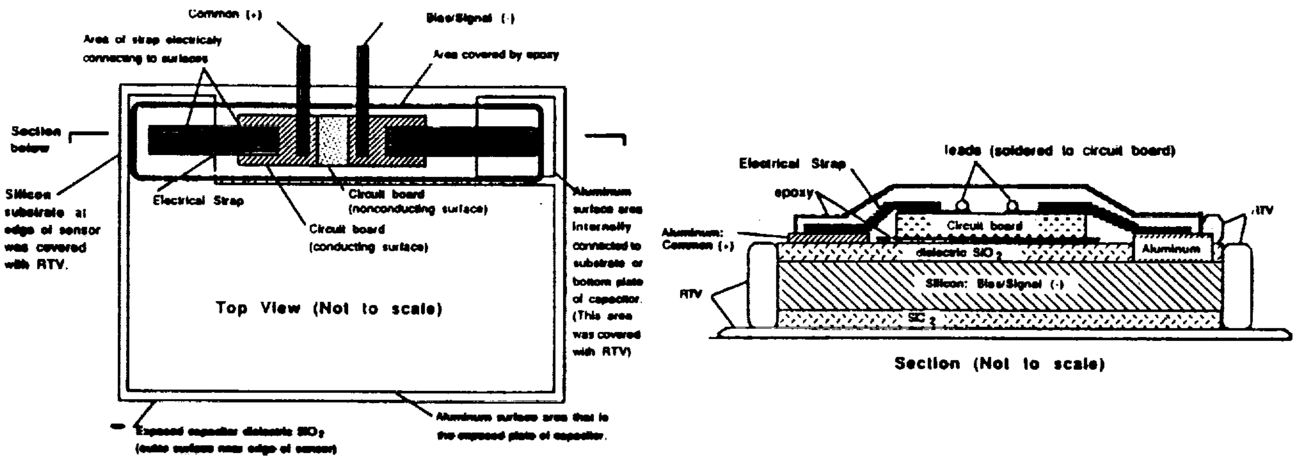
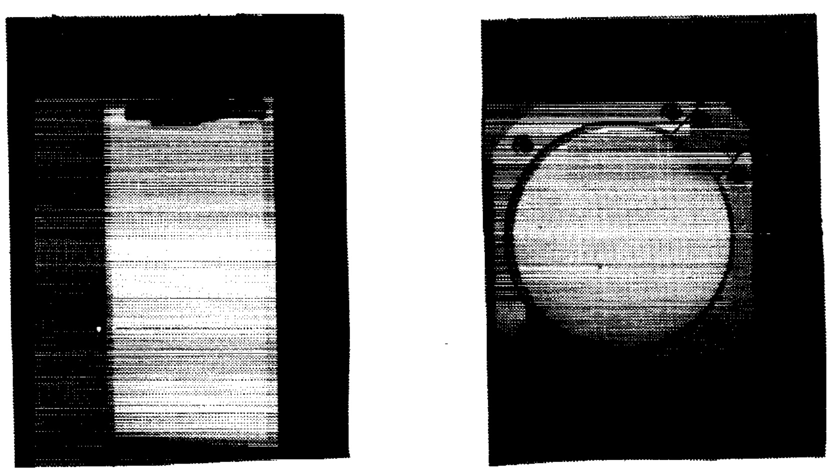


Figure 1. Schematic of the MOS detectors and electrical connections used on the OMDC Experiment. (Not to scale)

A photograph of an OMDC detector and, for comparison, a photograph of an earlier IDE detector are shown in Figure 2.



OMDC Detectors LDEF IDE & MTS Detectors

Figure 2. Photographs of the MOS detector used on the OMDC Experiment and the MOS detector used on the LDEF IDE and the MTS.

IV. Detector Installation

A total of 54 of the MOS detectors were installed, using RTV 566 adhesive, in a ring on the exterior of the ISA Spacecraft structure at the same time and in the same manner as the spacecraft solar cells were installed. The bonding of the detectors directly to the spacecraft surface, rather than installing the detectors in a mount that is mechanically fastened to the spacecraft, as was done on LDEF, resulted in significant weight savings. Photographs of the detectors mounted on the ISA Spacecraft are shown in Figure 3.

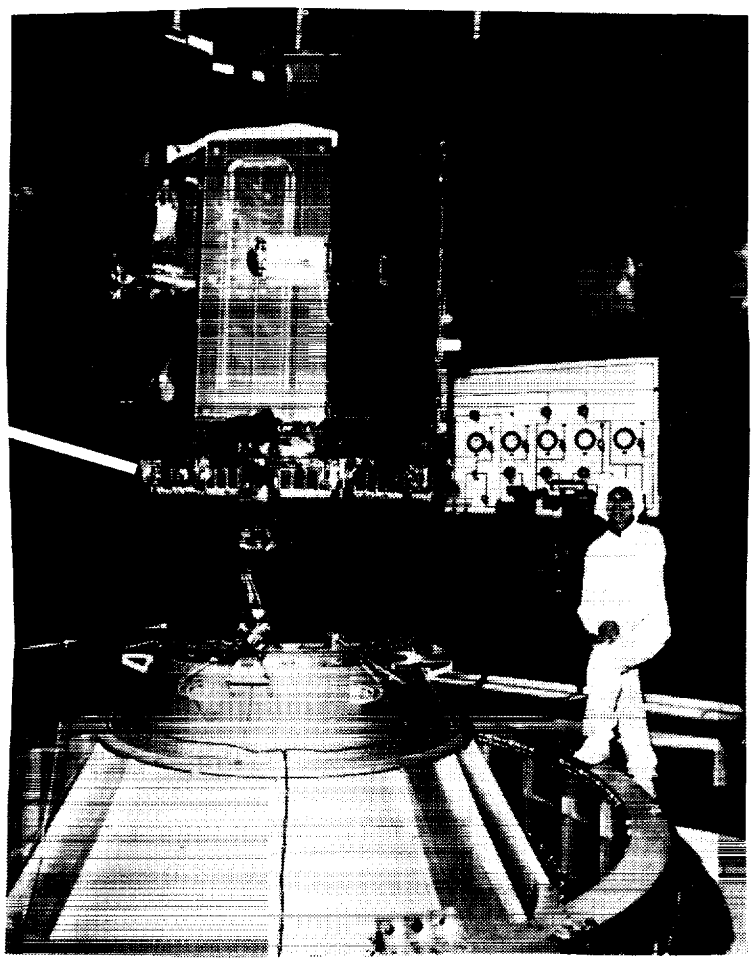


Figure 3. Photographs of OMDC Experiment detectors installed on the ISA Spacecraft.

After installation, the edges of the detectors were sealed with RTV 142 to prevent current leakage through any plasma that may exist on orbit around the spacecraft. Later, based on data from electrical status checks and on the observations that some of installed detectors were badly shadowed by other spacecraft parts, 48 of the 54 installed detectors were selected to be actively connected to the OMDC Experiment electronic system. The wiring harness connecting the selected detectors and the experiment electronics was also tacked to the spacecraft structure with RTV 142 adhesive. Both the RTV 566 and the RTV 142 were chosen for their low-outgassing properties and previous space use qualifications.

V. Electronic System

The selected 48 active detectors were electrically connected to form 3 arrays of 16 detectors each. Each array covered a 120° segment of the spacecraft surface. The 16 detectors in each array were electrically partitioned into 2 groups - one having 9 detectors and one having 7 detectors. This partitioning of one array of the detectors and the block diagram for the electronics associated with that array is shown in Figure 4.

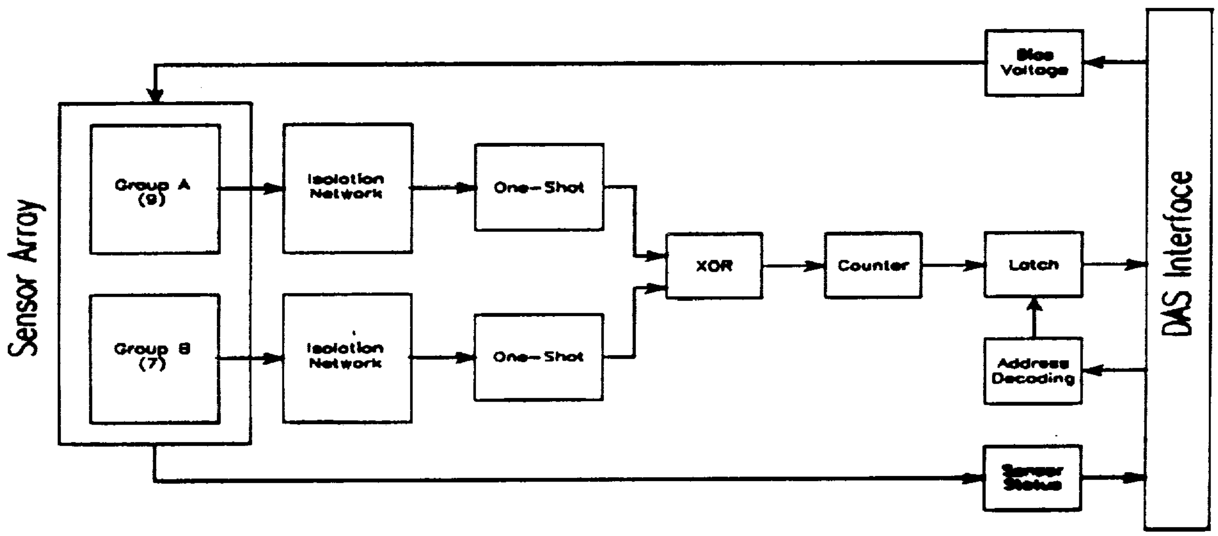


Figure 4. Block diagram of electronics associated with each of the 3 arrays of detectors.

Laboratory test data has shown that the MOS detectors require a minimum bias of 30 volts and a nominal operating bias of 43 volts. Since the load presented by the detectors was essentially capacitive, little drive current was required to achieve the bias. A 12 volt oscillator was created for use in the OMDC as an input to a voltage quadrupler. The output of the voltage quadrupler was then regulated to be the required 43 volt bias source. The bias supplied to each detector was current limited by a 2.2 meg. ohm resister to prevent overloading of the bias supply in the event a detector was permanently shorted.

The signal leads from each group of detectors were paralleled. A particle impact on one detector causes a temporary short which discharges that detector. An isolation network was used to prevent the other detectors in the group from also being discharged through this temporary short. A one-shot was used to sense the temporary shorting of an impacted detector. The output of this one-shot in each group, which was XORed to allow simultaneous detection of impacts on the other group in the same array, clocked a counter to record the total number of impacts for the entire array.

Each array was memory mapped by the ISA spacecraft Data Acquisition System (DAS). Each counter was isolated from the data bus by a Class C radiation hardened HCS245 to prevent the OMDC Experiment from seizing control of the data bus in the event of an experiment system failure. When the correct address for an array was decoded, the appropriate HCS245 latched the data and put it on the data bus to be read by the DAS.

The health of all of the OMDC Experiment in terms of the number of detectors that developed shorts was monitored by a status circuit. The leakage current of each array of detectors was converted to a voltage by a trans-impedance amplifier. Each status voltage was inputted to a passive summer whose output was buffered by a voltage follower. This signal was read by the DAS and converted to a digital word representing the overall health of the detectors.

The fault tolerance that could be built into the experiment electronic system was limited by the extremely severe power, size and weight constraints. Redundancy in the ground wiring of the detector harness was, however, implemented such that two breaks of ground wires would be required to lose more than one detector.

The ISA Spacecraft DAS sampled the array counters once every 5 seconds. If an impact was detected, the value of the counters and the value of the system clock was written to memory. The detector status was sampled by the DAS every 10 minutes and written to memory. The OMDC Experiment data was broadcast with the other ISA Spacecraft telemetry signals upon ground commands.

VI. Testing

The method used to install the MOS detectors on the ISA Spacecraft structure was verified in thermal/vacuum test and in vibration test that were run on a test assembly. The experiment electronic system was also subjected to thermal/vacuum and vibration test, and, it underwent complete functional, workmanship and acceptance testing as a unit before it was integrated into the spacecraft DAS. After the OMDC Experiment electronic system was installed in the DAS, it underwent further environmental, acceptance and performance testing as a part of the ISA Spacecraft.

VII. Data Obtained

The originally planned apogee altitude for the ISA Spacecraft was approximately 195,000 km and with that perigee the prelaunch orbiting lifetime was predicted to be greater than 1 year. The ISA Spacecraft actually achieved an apogee of only 127,000 km. With this lower apogee the spacecraft orbiting lifetime proved to be only 3 months and thus the data sample obtained by the OMDC Experiment was reduced. There were also other situations that developed with the ISA Spacecraft that have created some difficulties in analyzing the OMDC Experiment data. First, there were spacecraft telemetry command and receiving problems that resulted in the loss of precise timing data and thus the orbit position for some of the impact events that were detected. No impacts were lost however. The data obtained was more than adequate to demonstrate the excellent performance of the new MOS detectors that were used. The data was also adequate to provide valuable information on the natural meteoroid environment near the Earth and an indication of the variation in the man-made debris population with altitude.

The OMDC Experiment health status circuit indicated that all of the 48 active detectors probably remained operational for the entire mission duration - even the last several orbits when the perigee altitude was rapidly dropping. In a worse case scenario, no more that one or two of the detectors could have developed permanent shorts. Thus for analysis purposes, the active sensing area for the experiment during the mission was a well defined quantity. All other ISA Spacecraft housekeeping data that related to the OMDC Experiment indicated nominal performance of the experiment. The complete data set that was obtained is presented in Table I. The first column of the Table I presents the calendar date and time of broadcasts that contained new impact counts. The second and third columns lists the day of the year and the orbit respectively that new impact counts were recorded. The fourth and fifth columns lists the accumulated counts transmitted from each of the three array counters and the number of new events indicated by each array counter respectively. The sixth column lists the radial distance from the center of the Earth to the spacecraft location when a new event was detected. In those situations where multiple events were transmitted in a single transmission, the radial distance to the point of impact of the last of the multiple events only is known. The seventh and eighth columns lists the angle from perigee and the hours from perigee.

It should be mentioned that the ISA Spacecraft had no attitude control or attitude measuring systems, and the attitude motions of the spacecraft could not be predicted analytically. It was hoped that ground observations of the ISA Spacecraft during perigee passages would provide some indications of the orientation, but they did not. Since the detectors on the OMDC Experiment did not present equal detecting areas in all directions around the spacecraft, the unknown ISA Spacecraft orientation results in uncertainties in the analysis.

The early analysis of the data from the OMDC Experiment have been made and published.[9, 10]

VIII. Conclusions

The flight of the OMDC Experiment on the ISA Spacecraft has demonstrated that useful data can be obtained with small, light weight, low power and inexpensive instruments that are developed and flown in a short period of time. The experiment is evidence of the positive side of the trend to smaller, cheaper and quicker spacecraft. The OMDC Experiment has also demonstrated that the ultra-light weight new MOS detectors that were used are excellent detectors for use on future near Earth spacecraft to monitor the small mass man-made debris population and on interplanetary spacecraft to monitor map the natural meteoroid environments encountered during the mission.

TABLE I

Accumulated Impacts - OMDC Experiment on ISAS

			Accumulated				New Counts				Perigee	Hours from
Date	DOY	Orbit	C1	C2	C3	Total	C1	C2	C3	radial dist	Angle	Perigee
02/04/94 07:12	35.3005	138	1	2	2	5	1	2	2	1.33E+05	179.3	24.89
02/04/94 15:14	35.6348	138	2	2	2	6	1			1.27E+05	186.1	32.71
02/04/94 16:45	35.6981	138	3	2	2	7	1			1.23E+05	187.5	34.23
02/04/94 18:40	35.7780	138	3	2	3	8			1	1.18E+05	189.4	36.15
02/19/94 15:36	50.6500	145	5	3	4	12	2	1	1	1.22E+05	187.9	34.60
04/03/94 00:19	93.0133	165	8	6	6	20	3	3	2	1.33E+05	181.4	27.30
04/03/94 05:42	93.2379	165	8	6	7	21			1	1.27E+05	186.1	32.68
04/05/94 01:41	95.0707	166	8	6	8	22			1	1.33E+05	179.9	25.43
04/21/94 00:48	111.0336	173	11	8	8	27	3	2		2.26E+04	240.7	50.15
04/29/94 14:51	119.6189	178	11	8	14	33			6	1.19E+04	87.3	0.40
04/29/94 15:03	119.6274	178	11	8	15	34			1	1.57E+04	103.1	0.61
04/29/94 15:41	119.6535	178	11	8	16	35			1	2.60E+04	125.1	1.23
04/29/94 16:01	119.6676	178	11	8	17	36			1	3.09E+04	131.2	1.57
04/29/94 18:00	119.7505	178	11	8	18	37			1	5.39E+04	148.0	3.56
04/29/94 23:23	119.9749	178	11	8	19	38			1	9.30E+04	162.8	8.95
04/30/94 16:50	120.7014	178	11	8	20	39			1	1.33E+05	180.7	26.38
04/30/94 22:56	120.9562	178	11	8	21	40			1	1.27E+05	185.9	32.50
05/01/94 03:55	121.1635	178	11	8	22	41			1	1.13E+05	190.9	37.47
05/01/94 15:01	121.6261	178	11	8	23	42			1	4.24E+04	218.8	48.58
05/04/94 15:31	124.6467	180	12	8	24	44	1		1	1.27E+05	174.5	19.00
05/05/94 23:55	125.9968	180	12	9	24	45		1		1.32E+04	93.6	0.47
05/06/94 01:02	126.0435	180	12	10	24	46		1		3.12E+04	131.5	1.59
05/06/94 05:26	126.2264	180	12	11	24	47		1		7.43E+04	156.7	5.98
05/06/94 07:12	126.3005	181	12	11	25	48			1	8.62E+04	160.7	7.77
05/06/94 08:38	126.3603	181	12	12	25	49		1		9.44E+04	163.3	9.20
05/06/94 10:50	126.4519	181	12	13	25	50		1		1.05E+05	166.5	11.40
05/06/94 13:22	126.5573	181	12	13	26	51			1	1.15E+05	169.6	13.93
05/07/94 02:10	127.0909	181	12	13	27	52			1	1.33E+05	181.0	26.73
05/07/94 03:07	127.1300	181	12	13	28	53			1	1.32E+05	181.8	27.67
05/07/94 05:50	127.2435	181	12	14	28	54		1		1.30E+05	184.1	30.40
05/07/94 06:52	127.2865	181	12	15	28	55		1		1.28E+05	185.0	31.43
05/07/94 07:48	127.3250	181	12	16	28	56		1		1.27E+05	185.8	32.35
05/07/94 09:52	127.4114	181	12	17	28	57		1		1.22E+05	187.8	34.43
05/07/94 10:01	127.4176	181	12	18	28	58		1		1.22E+05	187.9	34.58
05/07/94 14:12	127.5923	181	12	19	28	59		1		1.08E+05	192.5	38.77
05/07/94 14:33	127.6067	181	12	19	29	60			1	1.07E+05	193.0	39.11
05/07/94 15:41	127.6538	181	12	19	30	61			1	1.02E+05	194.5	40.24
05/07/94 15:54	127.6629	181	12	19	31	62			1	1.01E+05	194.8	40.46
05/07/94 16:04	127.6696	181	12	20	31	63		1		9.99E+04	195.0	40.63
05/07/94 17:11	127.7165	181	12	21	31	64		1		9.42E+04	196.7	41.75
05/07/94 18:21	127.7650	181	12	22	31	65		1		8.76E+04	198.8	42.91
05/07/94 19:30	127.8125	181	12	23	31	66		1		8.05E+04	201.1	44.05
05/07/94 20:29	127.8537	181	12	24	31	67		1		7.35E+04	203.6	45.04
05/07/94 23:27	127.9773	181	12	25	31	68		1		4.72E+04	215.6	48.01
05/07/94 23:42	127.9876	181	12	25	32	69			1	4.45E+04	217.3	48.26
05/07/94 23:55	127.9969	181	12	25	33	70			1	4.20E+04	219.1	48.48
05/08/94 04:35	128.1915	182	12	25	36	73			3	3.39E+04	134.5	1.79
05/08/94 04:57	128.2067	182	12	25	37	74			1	3.86E+04	138.6	2.16
05/08/94 05:03	128.2111	182	12	25	38	75			1	3.98E+04	139.6	2.26
05/08/94 06:01	128.2512	182	12	25	39	76			1	5.05E+04	146.4	3.23
05/08/94 10:55	128.4555	182	12	26	39	77		1		8.82E+04	161.6	8.13
05/08/94 15:12	128.6339	182	12	27	39	78		1		1.09E+05	167.9	12.41
06/10/94 00:20	130.0143	182	12	28	39	79		1		6.57E+04	206.4	45.54
05/10/94 00:38	130.0267	182	12	28	40	80			1	6.32E+04	207.4	45.84

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