FFI RAPPORT

REPORT ON THE ASPOC COMMISSIONING

SVENES Knut, NARHEIM Bjørn

FFI/RAPPORT-2001/03961

FFIE/768/172

Approved
Kjeller 13 August 2001

Torleiv Maseng
Director of Research

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE
(when data entered)

REPORT DOCUMENTATION PAGE

1) PUBL/REPORT NUMBER	2) SECURITY CLASSIFICATION	3) NUMBER OF PAGES
FFI/RAPPORT-2001/03961	UNCLASSIFIED	35
1a) PROJECT REFERENCE	2a) DECLASSIFICATION/DOWNGRADING SCHEDULE	
FFIE/768/172	-	

4) TITLE
REPORT ON THE ASPOC COMMISSIONING

5) NAMES OF AUTHOR(S) IN FULL (surname first)
SVENES Knut, NARHEIM Bjørn

6) DISTRIBUTION STATEMENT
Approved for public release. Distribution unlimited. (Offentlig tilgjengelig)

7) INDEXING TERMS

	IN ENGLISH:		IN NORWEGIAN:
a)	Spacecraft	a)	Satellitt
b)	Magnetosphere	b)	Magnetosfære
c)	Potential control	c)	Potensialkontroll
d)		d)	
e)		e)	

THESAURUS REFERENCE:

8) ABSTRACT

This report constitutes a summary of the commissioning activities for the Aspoc instrument on the Cluster-II satellites. This work was carried out during the autumn of 2000, and the report covers the check-out activities for all the instruments. Some recommendations for future processes of this nature are also discussed.

9) DATE	AUTHORIZED BY This page only	POSITION
13 August 2001	Torleiv Maseng	Director of Research

ISBN-82-464-0530-6

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE
(when data entered)

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This report constitutes a summary of the commissioning activities for the Aspoc instrument on the Cluster-II satellites. This work was carried out during the autumn of 2000, and the report covers the check-out activities for all four instruments. Some recommendations for future processes of this nature are also discussed.

1 INTRODUCTION

The Cluster/Soho-mission is the first of several cornerstone projects of the European Space Agency (ESA). Its purpose is to study the interaction between the Sun and the Earth through the dynamic processes inherent in the intermediate regions which are constituted mainly by the solar atmosphere, the solar wind as well as the magnetosphere/ionosphere-system. In this respect this cornerstone mission represent the largest ever European effort in the field of space plasma physics.

Soho was launched in late1995, and despite some operational problems, the satellite continues to provide new insights into the dynamical nature of our star during the turn of the solar maximum. It is expected that the Soho mission will be extended at least until the end of 2002. The four Cluster satellites were originally launched in the inaugurating flight of the Ariane-5 launch vehicle. Unfortunately the satellites were destroyed in the explosion of the rocket, but ESA reacted quickly to rebuild the satellites and the instruments. Therefore Cluster-II was launched in the summer of 2000 from the Baikonor range in Kasakhztan. The mission has a nominal operation period of two years, and consequently there will still be possibilities for complementary observations utilizing both the Soho and the Cluster program.

The purpose of the Cluster program is to study magnetospheric processes by carrying out simultaneous observations from four identical spacecraft in coordinated orbits. In this way it is possible to overcome the ambiguities of space and time as well as obtaining information on different spatial scales from several key regions like the magnetospheric cusps and tail. This mission is the first of several which will obtain multi/spacecraft observations of space physics processes, which is of particular value when studying the interaction between various plasma regions as well as turbulent processes.

The Norwegian space physics community took the opportunity to become heavily involved in the Cluster mission through the newly acquired ESA-membership. At FFI the space physics group consequently became involved in two instrument consortia. Both the participation in Peace (Plasma Electron And Current Experiment) and Aspoc (Active Spacecraft POtential Control) are based on the extensive prior experience of the group in the fields of low energy electron measurements and construction of high voltage devices for space instrumentation. However, in the remainder of this report it will only be focused on the Aspoc instrument.

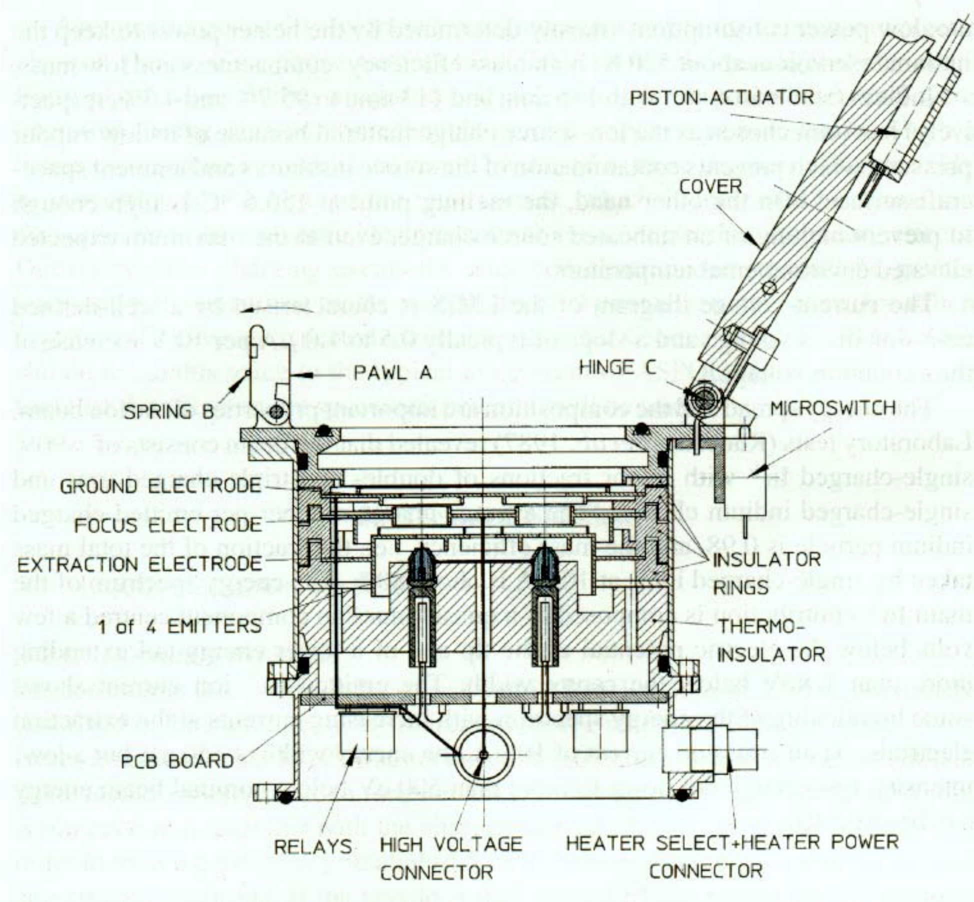

Figure 1.1 Schematic of an entire Aspoc-unit, showing the mechanical layout.

2 BACKGROUND

The purpose of Aspoc is to counteract the degrading effect of the solar UV-radiation on plasma measurements obtained from a spacecraft in the outer magnetosphere. This is accomplished by the emission of positive indium ions, which serve to balance the photo-electric current. The instrument is described thoroughly in (1) and references therein, and in figure 1.1 a schematic view of an Aspoc-unit is displayed.

The contribution of the Norwegian Defence Research Establishment consisted in designing APPENDIXand delivering the high voltage unit as well as a temperature control unit including the DC-DC
APPENDIX
APPENDIX
converter. These are described in (2) and (3), which also contains several test results. A block diagram of the high voltage unit is given in figure 2.1, and perhaps the most noteworthy feature here is the fact that each emitter module (containing four emitters each) is connected to a separate high voltage module. This provides for ample redundancy during the mission.

Some experience has already been gained with active spacecraft control (see (4) and references therein) previously, but the Cluster-II mission provides the first real opportunity for systematic and continuous operation. A report on the commissioning phase for Aspoc is therefore provided in the following text.

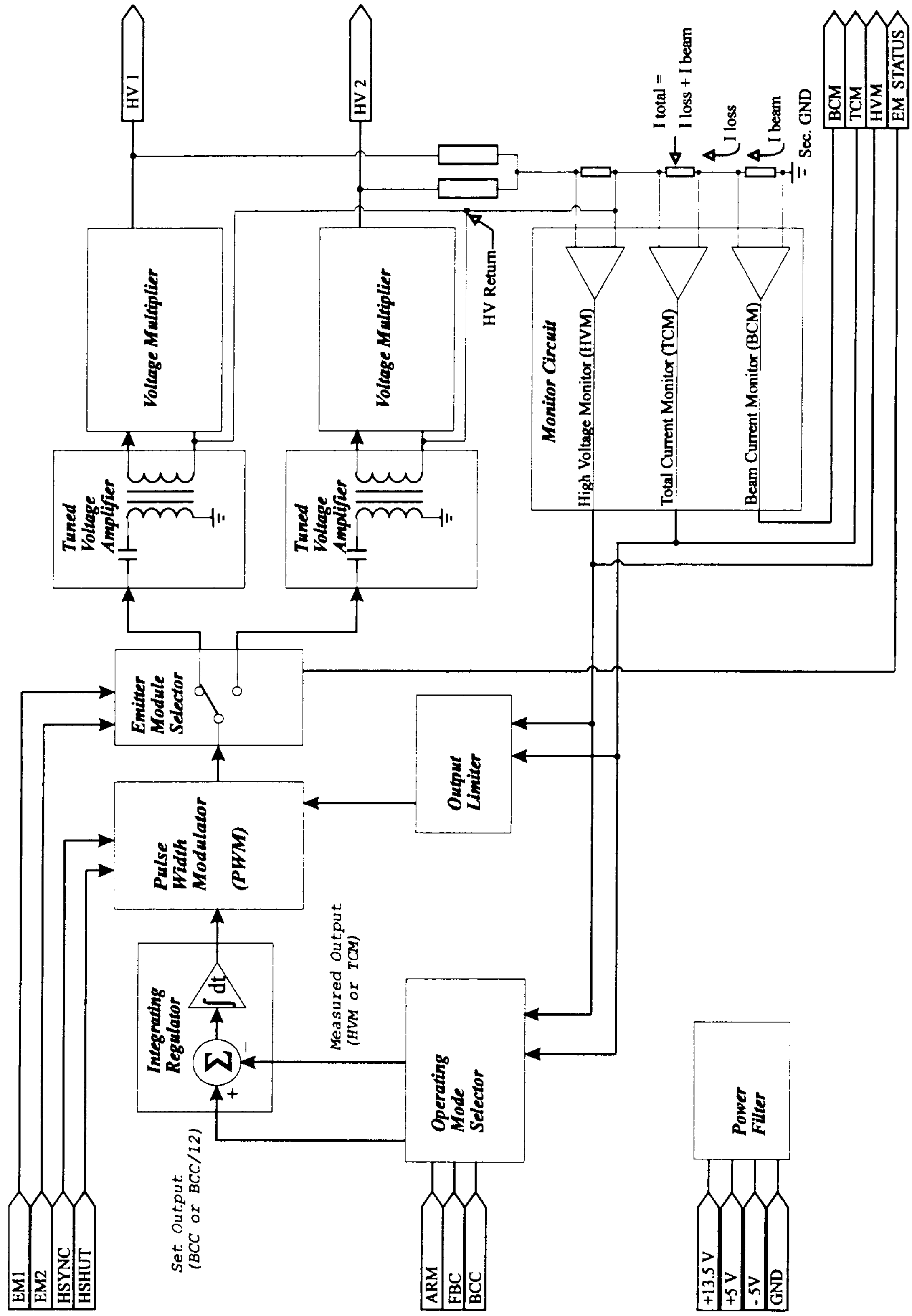

Figure 2.1 Block diagram of high voltage unit, highlighting the main modules.

3 THE INSTRUMENT CHECK-OUT PHASE

This phase is the important transition period from launch to routine operation, which requires especial attention from the experimenters during the initial tests of the instruments. The outcome of these exercises is the verification of the space worthiness and general abilities of the various experiments.

The first Cluster-II launch, carrying spacecraft two and three into orbit, occurred on 16th July and was a success. The second launch, carrying spacecraft one and four into orbit, occurred on 9th August and was also a success. It is here important to note that 24 days (more than three weeks) elapsed between these two launches. Finally, it should also be mentioned that the separation distances between the spacecraft are 600 km at this stage.

The commission phase started in earnest during the last week of August, and the various activities related to each spacecraft test are discussed separately in the following. Here each spacecraft are denoted by S/C-n where n is the unique identification number.

3.1 Spacecraft one (S/C-1)

The work discussed here was carried out during the night between 26th and 27th August of last year (2000). In this case the three participants were the PI K. Torkar (Technical University Graz, Austria) as well as the Co-I's M. Fehringer (Estec (ESA), Holland) and K. Svenes (FFI, Norway). The location was the European Satellite Operation Centre (ESOC) in Darmstadt, Germany. This was the very first Aspoc commissioning period.

The cover, protecting the needles during launch, was released on 17th August without problems. This was 9 days after launch and 17 days (only a little more than two weeks) before the commissioning period for this Aspoc unit. Since the instrument box is airtight, this also constitutes the most important time for outgassing. Due to a switch of spacecraft test schedule during this check-out period (S/C-2 was originally scheduled), this was 15 days less than anticipated based on the original plan.

The test plan included a preliminary high voltage (HV) test followed by the successive test emission of every needle in both units. This was uneventful for the first unit, but during the attempt to ignite emitter four in the second unit an anomaly occurred. This was probably a fatal high voltage discharge.

The high voltage test consisted of commanding each module separately to 1 kV, 4kV and 5 kV respectively before turning off. The read-out of achieved values showed that the high voltage units performed as expected in both cases. This test was performed just prior to the ignition test of both modules respectively. This test was successful.

The test of the needles consisted of stepping the high voltage towards gradually higher values until a return current is measured from the spacecraft, indicating that an ion current is escaping. The voltage stepping is an automatic procedure, which is limited by a threshold value. This value can be set by a ground command. An overview of the test results is given in table 3.1, which shows the most important values at the time of ignition of each needle.

	HV_{thr} (kV)	HV_{ig} (kV)	HV_{op} (kV)	Tot Cur (μA)	Ion Cur (μA)	Eff. (%)
Mod-1 Em-1	9	6.90	6.90	19.6	4.3	22
Mod-1 Em-2	8.5	7.14	7.14	12.5	4.7	38
Mod-1 Em-3	9	8.00	5.18	12.2	10.2	84
Mod-1 Em-4	9	7.29	7.29	19.6	19.4	99
Mod-2 Em-1	9	7.25	5.90	19.6	19.2	98
Mod-2 Em-2	n/a	n/a	n/a	n/a	n/a	n/a
Mod-2 Em-3	9	7.61	7.61	19.6	19.4	99
Mod-2 Em-4	10	No	No	-	-	-

Table 3.1 Summary of some check-out parameters for Aspoc on S/C-1 at commissioning.

As can be seen from table 3.1, all the emitters in module 1 did ignite. However, when testing emitter 4 in module 2 an anomaly occurred. After shutting down the entire unit an attempt was made to restart both module 1 and 2, but it was no longer possible to attain the commanded setting of the high voltage. Hence, it was concluded that a high voltage discharge had occurred. This was most likely a fatal accident.

Accordingly, all emitters in module 1 were tested whereas only two in module 2 could be tested satisfactorily. Of the six emitters which did ignite, four showed a good efficiency (>80%) whereas the two others were below 40% in efficiency. The latter two could hardly be operated on a routine basis throughout the mission. Hence, at the time of the discharge only two emitters were operative in both modules.

It should also be noted that all of the emitters which actually did ignite, did so at 8 kV or below. In fact, only two emitters needed significantly higher ignition voltage than operating voltage. Even so, the spread in operating voltage was quite significant varying between 5.2 kV and 7.6 kV as the extremes. In fact, this is almost 20% variation around the average value. These variations are most likely due to uncertainties in the production process. The most important parameters from this test are also displayed graphically in figure 3.1.

In addition, this unit was tested again on the night of 8th September to recheck on the condition. However, it was not possible to restart the high voltage system this time either. It should also be pointed out here that the HV connect monitor showed that the system is in a disabled state. From previous laboratory work it is known that such a situation would occur when a particular control chip was destroyed. Hence, these results unfortunately lend more credibility to the assumption that this unit has been subjected to a fatal high voltage discharge during the first test.

As a consequence, it has been decided that renewed attempts to restart the high voltage module on the Aspoc-unit on S/C-1 will only be made sparsely throughout the mission. However, the unit will routinely be left on to collect information on the potential of this spacecraft (these data are received from EFW and PEACE).

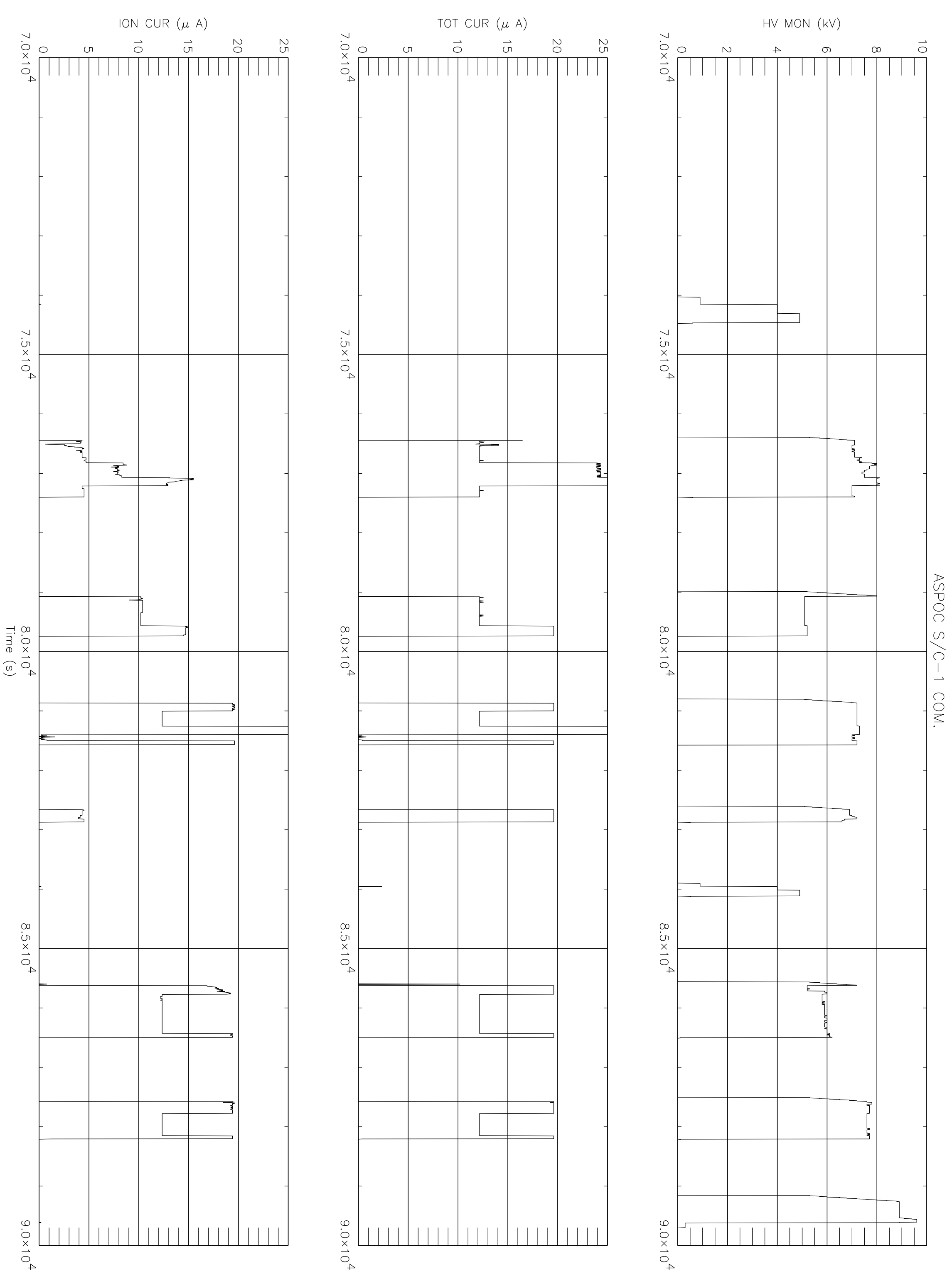

Figure 3.1 Overview of the first test results from S/C-1, showing the ignition of 5 emitters.

3.2 Spacecraft two (S/C-2)

The work discussed here was carried out during the nights of 8th and 10th September of last year (2000). In this case the three participants were the PI K. Torkar (Technical University Graz, Austria) as well as the Co-I's M. Fehringer (Estec (ESA), Holland) and K. Svenes (FFI, Norway). The location was the European Satellite Operation Centre (ESOC) in Darmstadt, Germany. This was the second Aspoc commissioning period.

The cover, protecting the needles during launch, was released on 25th July without problems. This was 9 days after launch and 45 days (more than six weeks) before the commissioning period for this Aspoc unit. Since the instrument box is airtight, this also constitutes the most important time for outgassing.

The high voltage test consisted of commanding each module separately to 1 kV, 4kV and 5 kV respectively before turning off. The read-out of achieved values showed that the high voltage units performed as expected in both cases. This test was performed just prior to the ignition test of both modules respectively. The test was successful.

The test of the needles consisted of stepping the high voltage towards gradually higher values until a return current is measured from the spacecraft, indicating that an ion current is escaping. The voltage stepping is an automatic procedure, which is limited by a threshold value. This value can be set by a ground command, and in this case it was 8 kV during the entire test period.

An overview of the test results is given in table 3.2, which shows the most important values at the time of ignition of each needle.

	HV_{thr} (kV)	*HV_{ig} (kV)*	*HV_{op} (kV)*	*Tot Cur (μA)*	*Ion Cur (μA)*	*Eff. (%)*
Mod-1 Em-1	n/a	n/a	n/a	n/a	n/a	n/a
Mod-1 Em-2	8	-	-	-	-	-
Mod-1 Em-3	8	-	-	-	-	-
Mod-1 Em-4	8	-	-	-	-	-
Mod-2 Em-1	n/a	n/a	n/a	n/a	n/a	n/a
Mod-2 Em-2	8	7.33	7.33	12.2	10.4	85
Mod-2 Em-3	8	6.70	6.31	12.2	9.6	79
Mod-2 Em-4	8	7.69	6.00	12.2	12.3	101

Table 3.2 Summary of some check-out parameters for Aspoc on S/C-2 at commissioning.

During testing of Module 1 the instrument went into a standby mode during testing of Emitter 2, leading to a reset of the unit. This happened after testing of Emitters 3 and 4, which did not ignite. The subsequent test of the high voltage unit showed no adverse effects. However, in order to stay on the cautious side, it was decided not to carry out further tests of this module for the time being.

However, as it turned out, the tests of module 2 yielded three emitters that performed very satisfactorily. In figure 3.2 an overview of the entire test period is displayed.

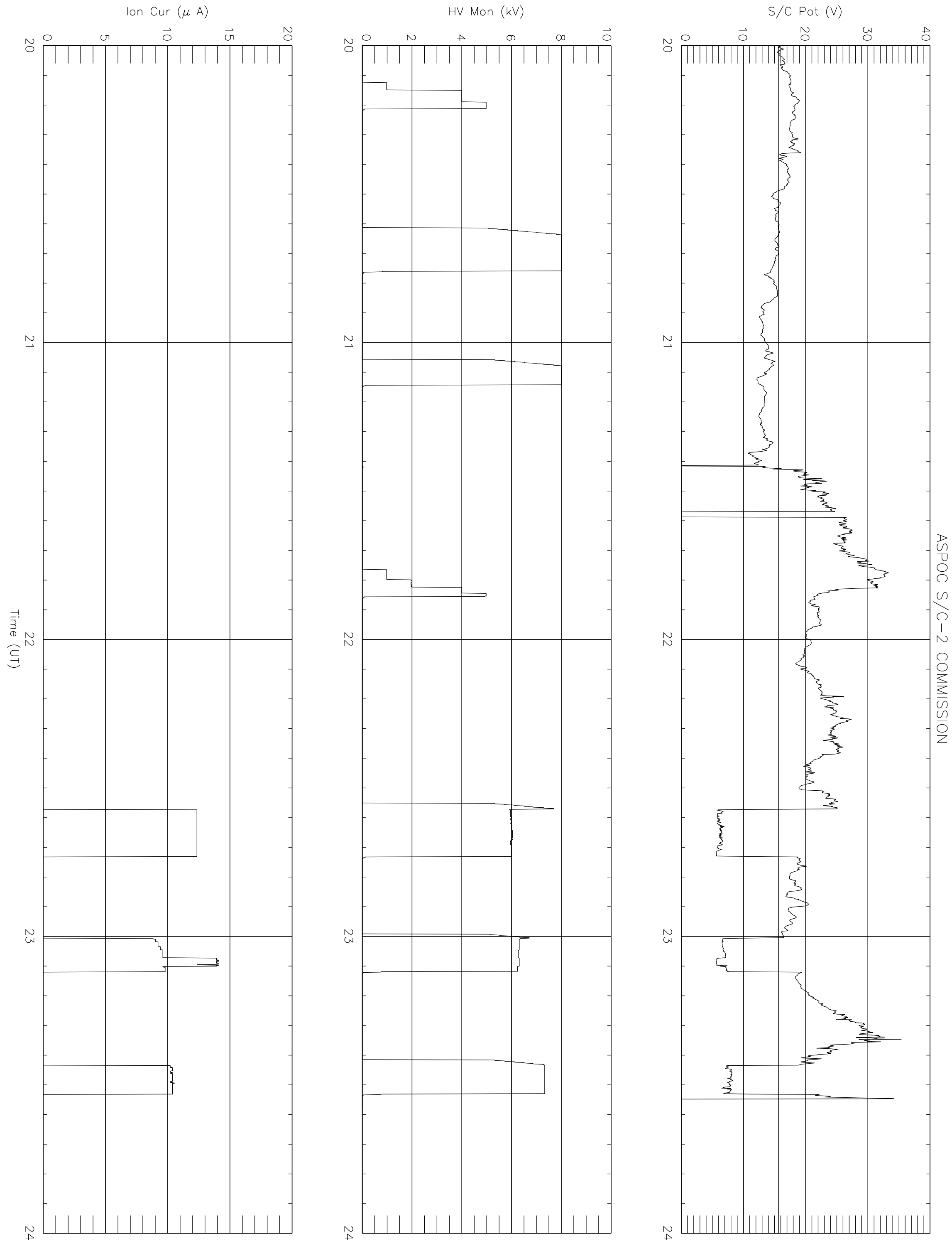

Figure 3.2 The first test results from S/C-2, also showing the effect on the potential.

Three emitters in module 2 all ignited and emitted ion current with an efficiency of 80% or better. Hence, all of these emitters are declared as operational. Since this is expected to give the equivalent to more than one year of operation, it was decided to only use this module and keep the other as a spare until further notice.

From figure 3.2 it can also be seen that the emission of indium ions had an immediate effect on the spacecraft potential. Each time the potential drop was significant, with the three emitters decreasing the spacecraft potential by 19 V, 10 V and 11 V respectively. Each of these values were accomplished with a nominal beam current of 12.25 μA only. Hence, from these examples it is already clear that Aspoc will significantly enhance the ability of the particle experiments throughout the duration of the mission.

It should be mentioned here that the spacecraft potential values were obtained from the electric field instrument (EFW), which provided potential measurements between the spacecraft and the floating spheres. Note though that the booms were only extended to a length of 15 m during this period, so the measurements only constitute a lower limit on the value of the spacecraft potential. Judging from the fact that the spacecraft was close to apogee and that the measured spacecraft potential reached fairly high values (more than 30 V), it is reasonable to assume that these tests were performed in the boundary region between the plasma sheet and the tail lobes. This is one of the main regions were it is expected that the operation Aspoc will be of great value for the plasma instruments, so it was reassuring to observe that the spacecraft was responding well even to this limited test operation.

In figure 3.3 a detail from the test period of emitter 3 is displayed. This shows the effect of a further current enhancement from an effective ion current of 9.5 μA to 14 μA which is almost a 50% increase. However, as is seen, this only lead to a further potential drop of 2 V or less. Consequently, at present it seems that it may not be worthwhile to increase the current from the lowest level except in special cases. Hence, the strategy will be to use a nominal ion current of 12.25 μA for continuous operation.

The second night (10th September) was then exclusively set aside to do cycling tests of the emitters which had already been shown to be operational. The fourth emitter in module 2 was chosen initially. However, after a short period of operation the instrument again entered stand-by mode. An immediate high voltage test showed that now damage had been done to the unit, but nevertheless this was an unexpected occurrence.

It was determined that the DPU put the instrument into this mode due to a weakness in the interaction between hardware and software. This situation occurs when current starts to flow from an emitter which is not heated to a high enough temperature to melt down all the indium in the container. The DPU will then order an HV increase in order to draw more current, but if the set limit is not reached before the HV passes the safety limit the instrument will be automatically put into the stand-by mode. This problem is described in more detail in appendix B. In addition, a resolution for a temporary work around of the problem is also described here.

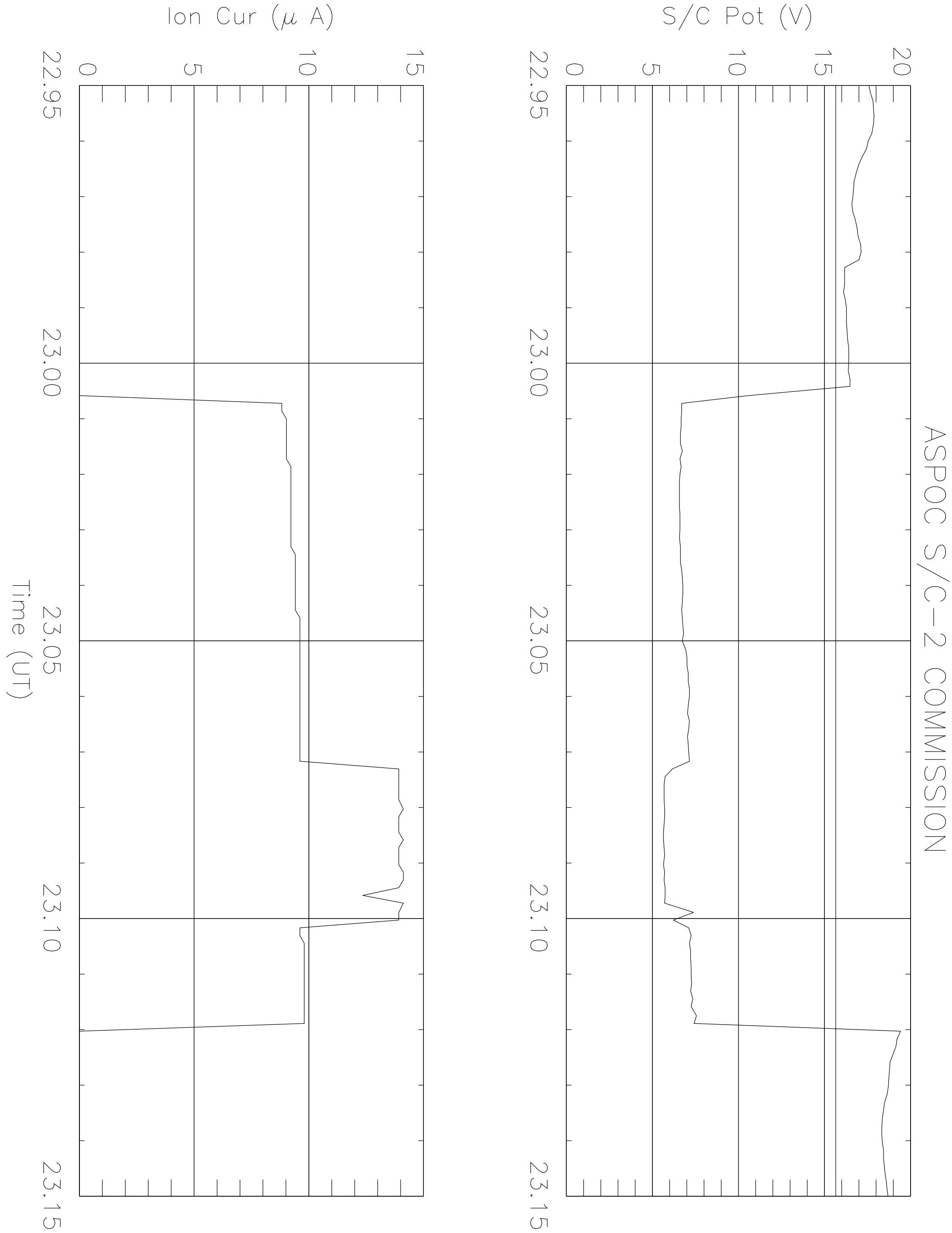

Figure 3.3 Detail from the test of emitter 3, showing the effect of a second current increase.

After adopting the new start-up procedure several more tests were carried out on this module during the reminder of the month. The results are summarised in table 3.3 below.

Filament	Test No	HV_{ig} (kV)	HV_{op} (kV)	Tot Cur (μA)	Tot Cur (μA)	Eff (%)
Mod-2 Em-2	1	7.33	7.33	12.16	10.59	87
Mod-2 Em-2	2	7.29	7.29	9.80	8.02	82
Mod-2 Em-2	3	7.25	7.27	9.80	8.82	90
Mod-2 Em-2	4	7.29	7.29	9.80	8.43	86
Mod-2 Em-2	5	5.37	5.33	9.80	8.63	88
Mod-2 Em-3	1	6.31	6.24	9.80	8.24	84
Mod-2 Em-3	2	6.31	6.24	9.80	8.43	86
Mod-2 Em-3	3	6.35	6.35	9.80	8.43	86
Mod-2 Em-3	4	6.35	6.31	9.80	8.82	90
Mod-2 Em-3	5	6.31	6.27	9.80	8.82	90
Mod-2 Em-4	1	7.84	5.80	5.10	4.90	96
Mod-2 Em-4	2	7.88	7.69	7.06	6.86	97
Mod-2 Em-4	3	7.69	7.65	9.80	9.61	98

Table 3.3 Statistics describing the start-up of the filaments in module two.

From the table it is seen filament two changed behaviour from the fourth to the fifth test ignition. A further attempt with the same needle showed a rapid decrease of the output current, which lead to the high voltage being increased to the threshold value in order to compensate. The emitter was then automatically turned off. Such behaviour is interpreted as self-contamination, and it has been observed in the laboratory previously.
Hence, this needle will not be used actively during routine operations.

In the case of filament four, the situation was the exact opposite. The first attempt to start it resulted in a low emitter current, but this increased by about 50% during the following two tests. This is symptomatic for filaments which are originally contaminated, but are cleansed during the first operation in orbit. Such behaviour is in accordance with previous space operations.

It is also noteworthy that all filaments in module two ignited below 8 kV during all tests. The operating voltages also turned out to such that ample margins exist with respect to the threshold value. This is reassuring in view of the expected long term operation of this unit during the mission.

The conclusion is that both emitter three and four are healthy, and both are considered available for use in the regular part of the mission. Emitter number three is the preferred one since the operation voltage (6.3 kV) is lower for this one. This is true even though the efficiency is slightly lower (90% compared to 97%). Hence, two needles are available on spacecraft 2 for the mission.

3.3 Spacecraft three (S/C-3)

The work discussed here was carried out during the 12th and 13th October of last year (2000). In this case the three participants were the PI K. Torkar (Technical University Graz, Austria) as well as the Co-I's M. Fehringer (Estec (ESA), Holland) and K. Svenes (FFI, Norway). The location was the European Satellite Operation Centre (ESOC) in Darmstadt, Germany. This was the third Aspoc commissioning period.

The test period included a high voltage test for each module. This test consisted in commanding each module to a voltage of 1 kV, 4 kV and 5 kV, respectively. In both cases the test was successful. Again the threshold value for ignition was set to 8 kV for all tests.

It should also be mentioned that during the second day of testing the spacecraft was quite close to perigee, so the unmodified spacecraft potential was not very high. Still, the effect of turning on Aspoc could readily be observed from the potential measurements in each case (see figure 3.4).

An overview of the test results is given in table 3.4, which shows the most important values at the time of ignition of each needle.

	HV_{thr} *(kV)*	HV_{ig} *(kV)*	HV_{op} *(kV)*	*Tot Cur (μA)*	*Ion Cur (μA)*	*Eff. (%)*
Mod-1 Em-1	8	7.29	7.25	9.8	9.61	98
Mod-1 Em-2	8	-	-	-	-	-
Mod-1 Em-3	n/a	n/a	n/a	n/a	n/a	n/a
Mod-1 Em-4	8	7.33	7.33	9.41	6.67	71
Mod-2 Em-1	8	6.75	6.75	9.8	9.61	98
Mod-2 Em-2	8	6.34	6.31	9.8	8.82	90
Mod-2 Em-3	8	6.55	6.67	9.8	9.61	98
Mod-2 Em-4	8	-	-	-	-	-

Table 3.4 Summary of some check-out parameters for Aspoc on S/C-3 at commissioning.

It is seen that ignition was achieved in five cases, but that the efficiency of filament four in module one was very low. As in previous such cases, it was assumed that the needle is contaminated and will not be used further. However, the other filaments all exhibited a high efficiency as well as maintaining low operation voltages.

In figure 3.4 an overview of the test results from this first day is displayed. As can be seen, these tests were carried out in a part of the orbit where the undisturbed spacecraft potential surpassed 40 V, but the operation of Aspoc still brought the spacecraft potential down to less than 10 V immediately. Hence, even with the low current values mostly used here (about 10μA) the potential change achieved was still 30 V or more.

Due to the smooth running in this test period, a possibility existed for igniting the emitters three times to increase the confidence in each. An overview of these re-tests is given in table 3.5, which shows the variations of some important parameters at the time of ignition of each emitter.

	HV_{ig} (kV)-1	Eff. (%)-1	HV_{ig} (kV)-2	Eff. (%)-2	HV_{ig} (kV)-3	Eff. (%)-3
Mod-1 Em-1	7.29	98	6.98	98	6.94	98
Mod-2 Em-1	6.75	98	5.92	98	7.02	98
Mod-2 Em-2	6.35	90	6.31	90	6.20	96
Mod-2 Em-3	6.55	98	6.86	99	5.76	102
Mod-2 Em-4	-	-	-	-	n/a	n/a

Table 3.5 Summary of parameters during re-testing of Aspoc on S/C-3 at commissioning.

As seen from table 3.5, ignitions were again achieved regularly at relatively low voltages and with high efficiency. The test results from this day are displayed in figure 3.5, which gives an overview of the entire activity. In all it is clear that this unit contained four very good emitters. Hence, this constitutes the best test period carried through so far.

From figures 3.4 and 3.5 it is also seen that some tests using variable emitted current were carried through. This had two main objectives. First, it presents an opportunity to assess the responsiveness of the filaments to current increases. Technically it should here be noted that this generally leads to a somewhat decreasing efficiency of the filaments. This is related to the loss processes internal to extraction and beam focusing electrodes, which are increasing at higher current levels. From a technical point of view it is consequently advantageous to run the filaments at a steady low current level.

It is also clear from these tests that a further increase (with respect to the initial 10 μA level) of emitted current usually succeed in lowering the spacecraft potential with a couple of extra volts only compared to the effect of the initial decrease. Therefore, during actual operations, it must be considered whether the incremental improvement brought about through the small extra potential decrease outweighs the technical concerns for using a varying current level. Since of course also the finite indium source must be considered, it seems likely already at this early stage that the overall argument will point in favour of using a steady 10 μA as the default operational mode.

As a consequence, it has been decided to utilise only one of the filaments in each unit during routine operation. There are several reasons for doing this. First of all, it is to gain early experience of long term operation of a filament. Secondly, this avoids the problem of possible cross-contamination between filaments in the same module. Finally, it is also more convenient from an operational point of view.

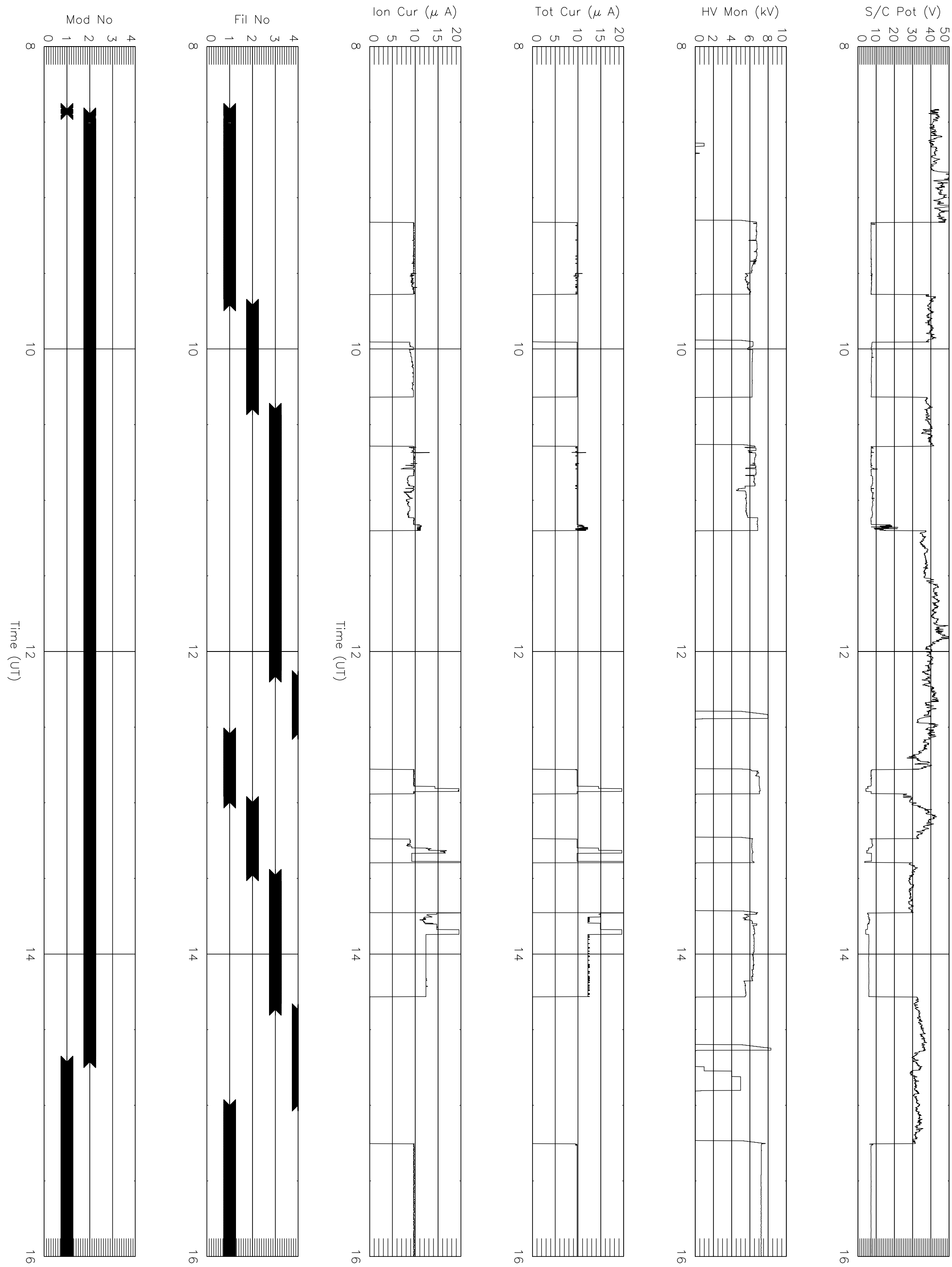

Figure 3.4 Overview of test results from S/C-3, first day.

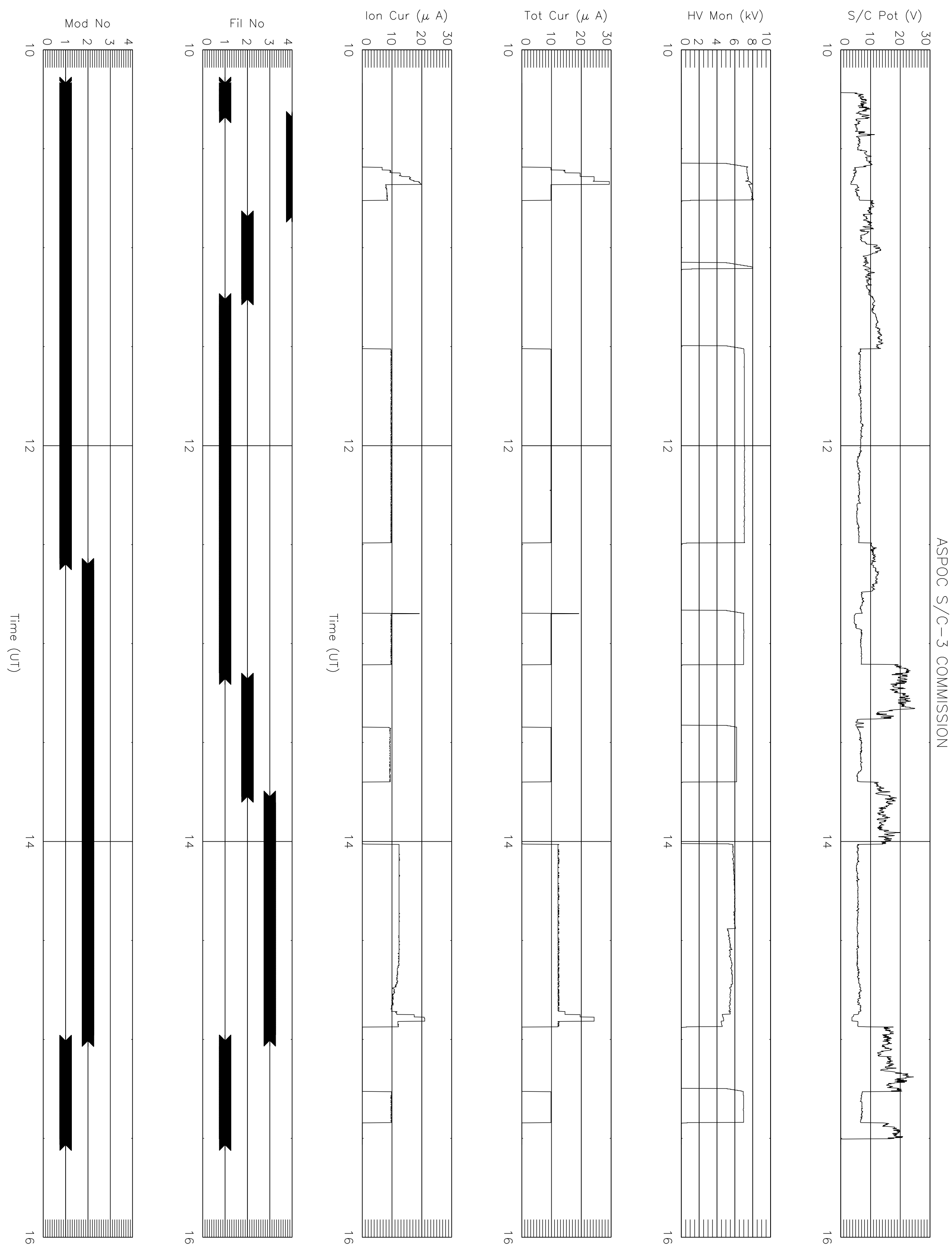

Figure 3.5 Overview of test results from S/C-3, second day.

3.4 Spacecraft four (S/C-4)

The work discussed here was carried out during the 27th October and 1st November of this year (2000). In this case the three participants were the PI K. Torkar (Technical University Graz, Austria) as well as the Co-I's M. Fehringer (Estec (ESA), Holland) and K. Svenes (FFI, Norway). The location was the European Satellite Operation Centre (ESOC) in Darmstadt, Germany. This was the fourth Aspoc commissioning period.

As it turned out, the first day was rather slow since only one emitter ignited with the high voltage threshold of 8 kV used during this test. Consequently, the high voltage threshold was increased to 8.3 kV for the tests on the second day. An overview of these results is given in table 3.6, which shows the most important values at the time of ignition of each needle.

	HV_{thr} (kV)	*HV_{ig} (kV)*	*HV_{op} (kV)*	*Tot Cur (μA)*	*Ion Cur (μA)*	*Eff. (%)*
Mod-1 Em-1	8.3	-	-	-	-	-
Mod-1 Em-2	8.3	-	-	-	-	-
Mod-1 Em-3	8.3	7.49	6.82	9.8	9.8	100
Mod-1 Em-4	8.3	-	-	-	-	-
Mod-2 Em-1	8.3	8.00	8.04	9.8	5.1	52
Mod-2 Em-2	8.3	-	-	-	-	-
Mod-2 Em-3	8.3	8.08	4.47	9.8	9.8	100
Mod-2 Em-4	8.3	8.16	7.37	9.8	9.8	100

Table 3.6 Summary of some check-out parameters for Aspoc on S/C-4 at commissioning.

It is seen from table 3.6 that altogether four emitters ignited during these tests. Three of the emitters even yielded ion currents at a very good efficiency, but two of them needed a very high voltage in order to ignite. Hence, from this test it seems likely that emitter three on module one would be the best emitter to use during routine operations.

Due to the initial problems a third day of testing was allocated to this spacecraft. Since it is known that the operation voltage of the emitters may decrease after some use, it was decided to re-ignite some of the emitters. Indeed, emitter four on module two and emitter three on module one this time ignited at 6.74 kV and 6.98 kV, respectively. The high voltage threshold was then increased even further to 8.5 kV. It was then possible to ignite emitter four on module one right at the limit. A similar attempt to ignite emitter two on the same module failed.

A statistical overview of these additional tests is given in table 3.7, which shows the variations of values of some important parameters at the time of ignition of each emitter.
As is seen, the formerly mentioned emitters operate with satisfactory efficiency at acceptable voltage levels on this satellite. A couple more emitters are available at high efficiency but at marginal ignition voltages, and these are consequently kept as spares for the time being.

Filament	Test No	HV_{ig} (kV)	HV_{op} (kV)	Tot Cur (μA)	Tot Cur (μA)	Eff (%)
Mod-1 Em-3	1	7.49	6.82	9.80	9.80	100
Mod-1 Em-3	2	6.94	6.94	9.80	9.80	100
Mod-1 Em-3	3	6.98	6.98	9.80	9.80	100
Mod-1 Em-4	1	8.51	7.96	9.80	9.80	100
Mod-2 Em-1	1	8.00	8.04	9.80	5.10	52
Mod-2 Em-1	2	8.00	8.00	9.80	5.10	52
Mod-2 Em-3	1	8.08	4.47	9.80	9.80	100
Mod-2 Em-3	2	8.08	4.47	9.80	9.80	100
Mod-2 Em-3	3	7.88	4.35	9.80	9.80	100
Mod-2 Em-4	1	8.16	7.37	9.80	9.80	100
Mod-2 Em-4	2	8.16	7.37	9.80	9.80	100
Mod-2 Em-4	3	8.08	7.76	9.80	9.80	100
Mod-2 Em-4	4	7.45	6.75	9.80	9.80	100

Table 3.7 Summary of parameters during testing of Aspoc on S/C-4 at commissioning.

The test results from this day are also displayed in figure 3.6, which gives an overview of the entire activity. Again it is noted that using current levels of 10 μA maintain a spacecraft potential reduction of more than 20 V at a regular basis.

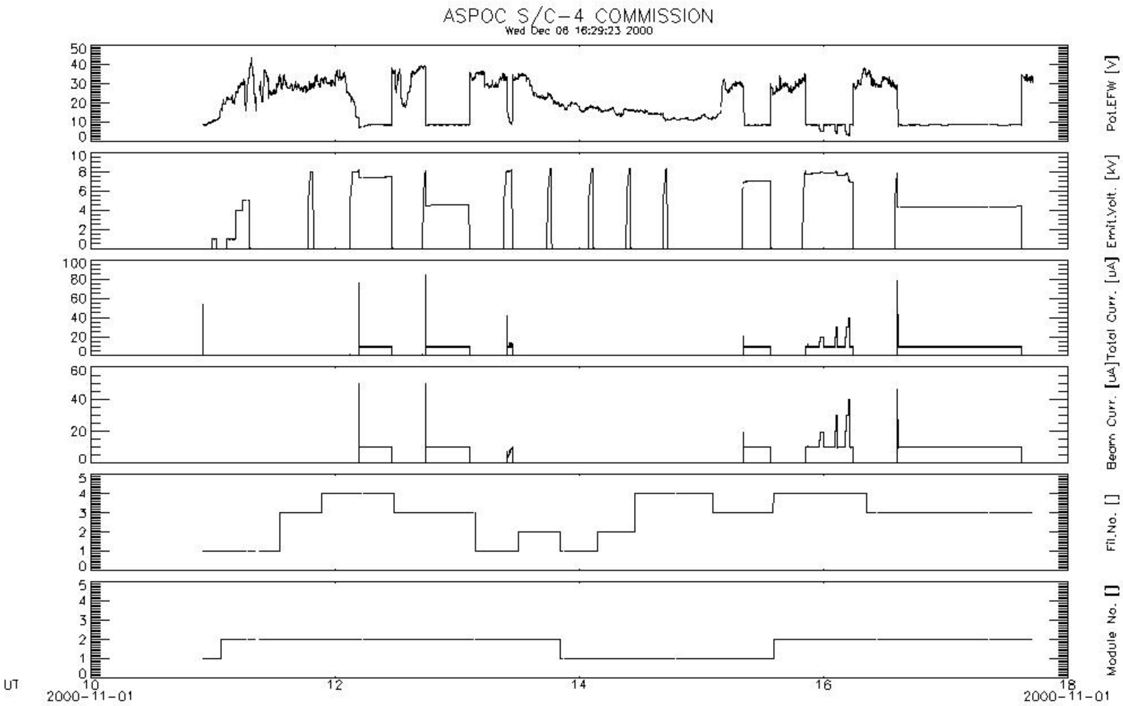

Figure 3.6 Overview of test results from S/C-4 commissioning.

3.5 Testing with Aspoc and Peace simultaneously

These measurements were also obtained during the commissioning phase. Several tests of Peace and Aspoc operating simultaneously were performed on 22nd November 2000. During this period the spacecraft were travelling through the magnetosphere some way inside the magnetopause in the afternoon sector. The undisturbed spacecraft potential was above +20V, but the operation of Aspoc kept it below +10 V.

Figure 3.7 shows the result of one particular test where the Aspoc current levels were gradually increased. The two upper panels show the variation of spacecraft potential as function of emitted ion current. It should be noted here that the potential is kept steady at low values even though the ambient plasma conditions obviously varies significantly during this period. This is reflected in the fact that the undisturbed spacecraft potential is much higher at the end of the test period as compared to the start, indicating that the spacecraft has moved into a region with much less plasma density.

The three lower panels show the corresponding electron measurements obtained by Peace during this period. These are measurements in the direction of the solar panels (top), radial away from the spacecraft surface (middle) and anti-parallel to the solar panel direction (bottom). By studying these spectrograms, it is clearly seen that the photo-electron population is strongly correlated to the emitted ion current. In fact, by increasing the ion current up to 40 µA most of the photo-electrons are allowed to escape the vicinity of the spacecraft (around 1630 UT).

In addition, there is also the matter of asymmetries at low energies between anodes pointing towards the solar panels and away from them (most photo-electrons in the anodes pointing towards the solar panels). This becomes somewhat less conspicuous when the Aspoc current was increased, but this is not of enough relevance to request Aspoc operating regularly at such high current levels.

Finally, it is important to note that the decrease of the level of spacecraft generated “contaminating” electrons also reveals “new” ambient plasma populations at least in the energy range below 100 eV. An example of this can be seen in figure 3.8 where electrons measurements obtained on two different spacecraft are compared. These measurements were obtained on 14th January 2001 when the Cluster spacecraft were moving outwards from perigee. During the period of interest, between about 05 UT and 09 UT, the radial distance increased from about 7 R_e to almost 11 R_e.

On S/C-2 (where Aspoc was operated) a distinct electron population with energies in the range 10 - 90 eV is readily apparent in all three anodes, even with some temporal structure clearly seen. However, when examining the same region of the S/C-1 data (without Aspoc) this population is completely swamped out by “artificial” electrons from the spacecraft surface. In fact, this electron population would likely have gone undetected if data from S/C-2 had not been available. Hence, operating Aspoc also facilitates the detection of “new” ambient electron populations with energies even up to 100 eV. This is an important aspect when assessing the origin of plasma in the various magnetospheric regions.

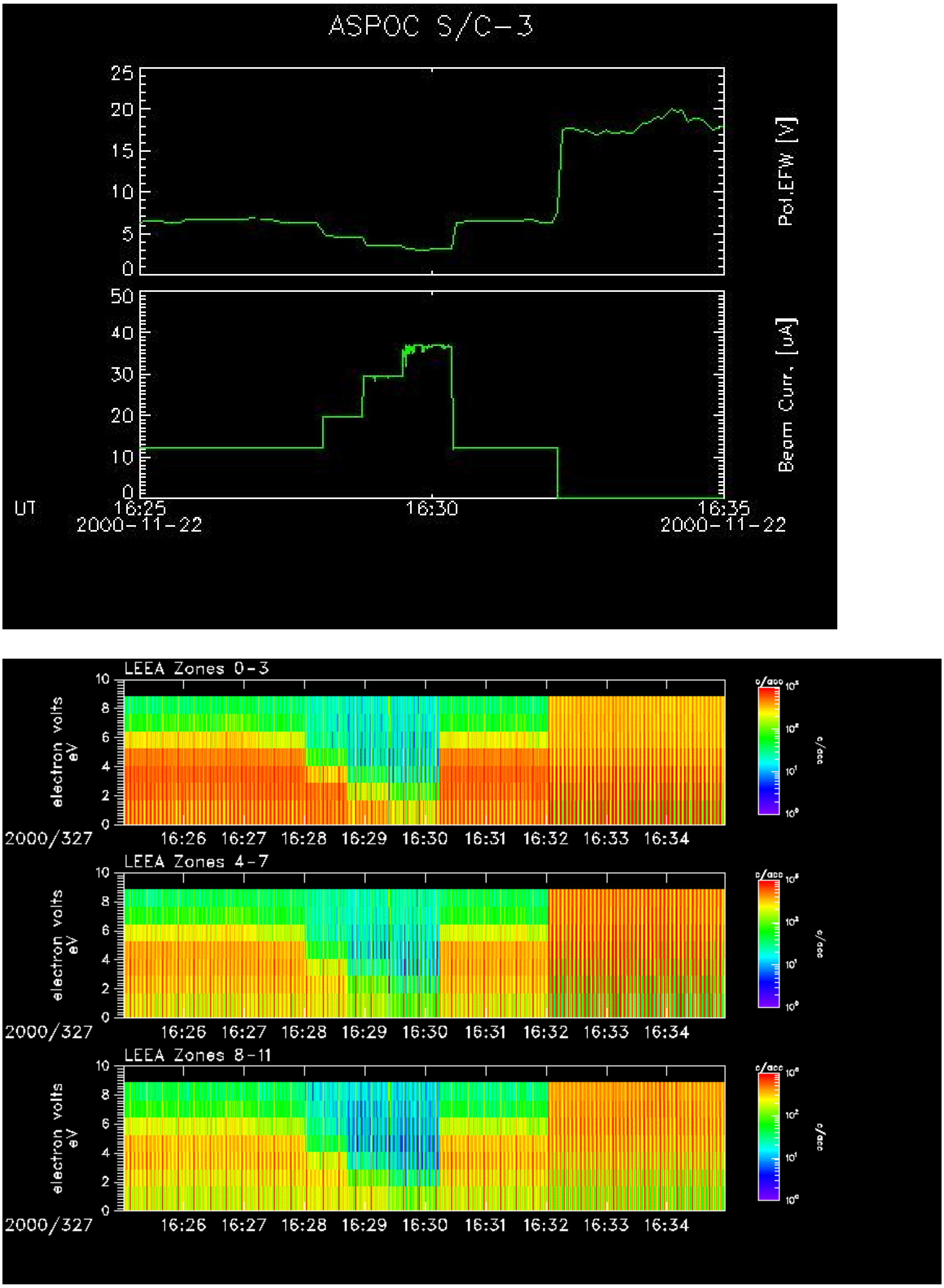

Figure 3.7 Measurements from S/C-3 during commissioning. Spacecraft potential and Aspoc current (top) plotted along with low energy electron measurements (bottom) obtained by Peace.

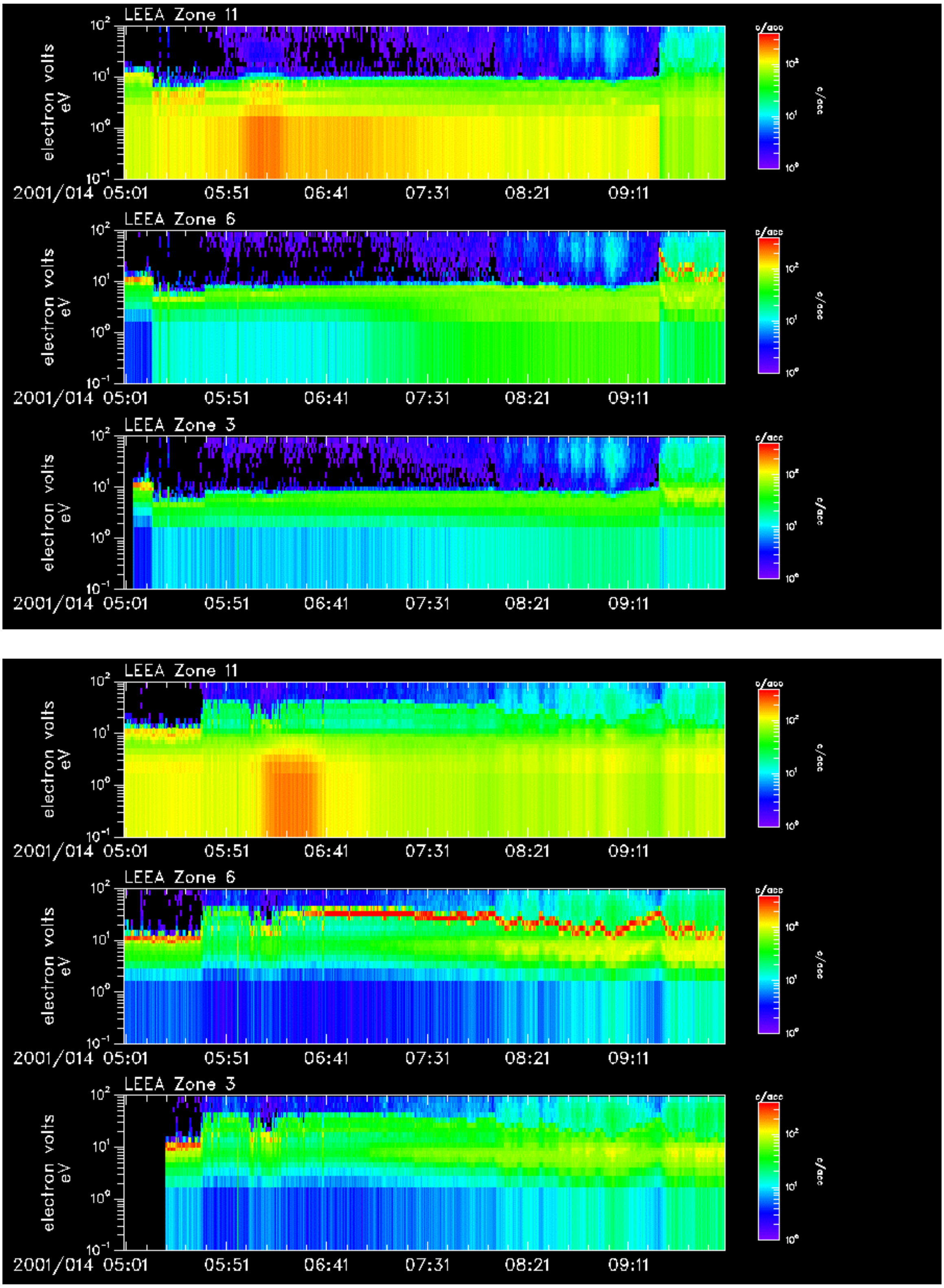

Figure 3.8 Electron measurements from S/C-2 (top) and S/C-1 (bottom) during commissioning. During this period Aspoc only controlled the potential of S/C-2 (top), giving rise to significant differences in the low energy electron measurements obtained by Peace.

4 DISCUSSION AND SUMMARY

The bulk of the commissioning work was accomplished during the autumn of 2000, and it has been described in the preceding text. This work is summarised in table 4.1 below.

Spacecraft	Emitter	HV Ignition	Efficiency	Evaluation
S/C-1	none	n/a	n/a	Non-functional
S/C-2	Mod-2 Em-2	-	n/a	Contaminated
	Mod-2 Em-3	6.3 kV	90%	Good
	Mod-2 Em-4	7.8 kV	97%	Good
S/C-3	Mod-1 Em-1	7.0 kV	98%	Good
	Mod-2 Em-1	6.6 kV	98%	Good
	Mod-2 Em-2	6.3 kV	92%	Good
	Mod-2 Em-3	6.4 kV	99%	Good
S/C-4	Mod-1 Em-3	7.1 kV	100%	Good
	Mod-1 Em-4	8.5 kV	100%	Too high voltage
	Mod-2 Em-1	8.0 kV	52%	Too low efficiency
	Mod-2 Em-3	8.0 kV	100%	Available
	Mod-2 Em-4	8.0 kV	100%	Available

Table 4.1 Overall statistics for start-up attempts of Aspoc-units during the autumn of 2000.

This represents the outcome of the work carried out to characterise the emitters on the various spacecraft, and as such constitutes the foundation for decisions to be taken during the operational phase of the mission. The main conclusion to be drawn here is that there are functioning units on three of the spacecraft containing more than one operative emitter each. Hence, this constitutes the necessary resources as well as back-up possibilities to carry out the objectives of the experiment.

It should also be noted that during the cause of this work it was decided to increase the ignition threshold to 8.3 kV, which is just a 4% increase on the initial value (8 kV). This was seen as a prudent step in order to provide margin for operation of a few additional needles at the same time as experience has shown that safety issues are not compromised.

Here it is also important to underline the events leading up to the fatal discharge occurring in the unit on spacecraft one on 27th August 2000, leaving this spacecraft without any potential control device. As was described in detail previously, a total of six ignitions were successfully achieved on several of the emitters contained in this experiment unit before the event occurred. From this it can be concluded that the hardware was functioning as specified, and in particular the high voltage unit and the DC-DC converter provided by the Norwegian Defence Research Establishment were both performing flawlessly up to that point.

However, the high voltage threshold was then increased well above the nominal value of 8 kV (to facilitate the ignition of the remaining emitters) a discharge finally occurred which damaged a multiplexer chip in the emitter monitor circuit. This inhibited any further operation of the instrument. The cause of this unfortunate event was deemed to be insufficient outgassing of the spacecraft, and as such this event must be classified as the result of a faulty test-out procedure. This has later been rectified by establishing an operational rule forbidding the setting of the threshold value above 8.5 kV for the remainder of the mission.

In addition to the commissioning activities reported on here, an interference campaign was also carried through into the early part of 2001. For the most part no detrimental effects of Aspoc-operation was reported from the other instrument teams. However, at times when the spacecraft are crossing regions of low plasma density, the escaping photo-electrons (due to Aspoc operating as preconceived) constitutes a significant noise signal in the electric field measurements. During the operation phase, this problem will be solved by establishing a procedure for time sharing between these two instruments.

The overall conclusions from the commissioning phase were then presented at the Comissioning Review on 1st February 2001. These can be summarised as follows:

- Aspoc is capable of reducing the spacecraft potential at a routine basis to eg. +7 V (at 10 µA ion current) or +5 V (at 20 µA).

- Aspoc also reduces natural fluctuations of the potential and provides a stable environment for plasma measurements.

- A reduction of the spacecraft potential to +7 V is considered as a significant improvement to plasma measurements in comparison with free floating potentials of up to +50 V; therefore the default ion current for nominal operations has been set to 10 µA.

- In order to maximise the scientific return from the Indium resources available, operations will be concentrated on regions where the predicted plasma density would lead to uncontrolled potentials significantly exceeding +7 V.

Hence, the instrument is capable of fulfilling the design objectives and is ready for the nominal operational phase. This is at the moment envisioned to continue throughout the year 2001, but it is deemed as very likely that an extension will follow.

5 CONCLUSIONS

During the commissioning phase all ion emitters have been characterised, and the emitters to be used during nominal operations have been selected. The activities carried out during this period can briefly be summarised as in table 5.1 below.

Spacecraft	S/C-1	S/C-2	S/C-3	S/C-4
Emitter turn-on's	6	29	26	26
Operating voltage	5.3-7.8 kV	5.8-7.5 kV	6.2-8.0 kV	4.4-8.0 kV

Table 5.1 Statistical overview of commissioning activities.

On S/C-1 a fatal discharge occurred on 27th August 2000, probably due to insufficient outgassing. Hence, this event must be classified as due to a faulty test-out procedure.

The main conclusion to be drawn here is consequently that there are functioning Aspoc-units on three of the spacecraft containing more than one operative emitter each. Hence, this constitutes the necessary resources as well as back-up possibilities to carry out the all the scientific objectives of the experiment. In particular, it can be stated that the high voltage units and the DC-DC converters, provided by the Norwegian Defence Research Establishment, are all performing flawlessly in space.

It has also already been proved that Aspoc is capable of maintaining the spacecraft at a low steady potential at a regular basis. This will significantly enhance the ability of the low energy plasma instruments to perform their routine measurements.

Hence, it can be clearly stated that the Aspoc-instrument is ready for the nominal mission operation phase. This is at the moment envisioned to continue throughout the year 2001, but it is deemed as very likely that an extension will follow.

Acknowledgement
The authors wish to express their appreciation of the competent work, as well as positive attitudes during the long nights of testing, to the PI Klaus Torkar (Technical University Graz, Austria) as well as Co-I’s Michael Fehringer (Estec (ESA), Holland). We also want to emphasis the excellent work of the instrument engineers Kirsten Kvernsveen and Bård Kyrkjedelen of the Norwegian Defence Research Establishment, whose contributions were invaluable to the success of this experiment.

A: Comments on the discharge event on s/c-1

In view of the unfortunate probable discharge event during the commissioning of Aspoc on S/C-1, a few additional security precautions should be added to the check-out procedures to avoid such mishaps in the future. It is very likely that if such considerations are worked through prior to the actual commissioning, the probability for meeting with success will be enhanced significantly.

The main issue under discussion here is the procedure for increasing the high voltage in order to achieve ignition of all the needles. It is already well known that some needles need a higher than average voltage in order to respond. This is most likely due to imperfections during the production process. It is also of importance to ignite the individual needles as soon as possible, since inactivity further degenerate the efficiency of the needles.

However, it is also clear that the higher the voltage is increased the larger the risk of a fatal discharge becomes. This risk also increases the less time has elapsed during the outgassing period. Hence, these two considerations may often come into conflict with each other and some systematic method of resolution is therefore needed. This method also needs to be developed outside of the more stressful atmosphere of an actual commissioning situation.

The exact voltage level to make a particular needle emit current is difficult to quantify, and in addition it may vary with time. Also, the exact nature of a high voltage discharge has an inherently random component as well as an ill defined dependency on outgassing time. This makes a well funded decision extremely difficult to come by in any given case.
Hence, to avoid getting into a situation where some “black magic” like hunch precedes over decision a more suitable tool has to be invoked.

Therefore some statistical considerations have to be taken into account in order to resolve such problems. It is generally assumed that each unit has to be operative for about 11000 hours during the nominal mission. Since it is expected that no single emitter will last for more than 2000 hours, this means that six emitters in each unit must be ignited. However, in a situation like this the threshold value for the high voltage should be conservatively set. Hence, it is recommended that a threshold value above 8 kV is not allowed during the first round of commissioning. If higher voltages are needed, further time should be allowed to elapse to increase the probability of adequate outgassing.

B: Detailed discussion of anomaly during operation on 10th September

The detailed description is stated in email correspondence from the PI:

“In the first operation heating took the maximum time (start-up temperature was not reached)
= 156 frames. HV was turned on when P=0.74 W, U=12.5 V, I=58.8 mA. T=287 deg.

In the second start-up the start-up temperature 299 deg was reached already after 121 frames, and P=0.72 W, U=12.6 V, I=57.3 mA, T=305 deg.

After the same time (121 frames) during the first operation the values had been for comparison:
P=0.72 W, U=12.0 V, I=59.6 mA, T=257 deg.

In the second operation the electronics was still on 4-6 degrees, whereas in the first operation it had already increased to 12-14 deg, but this cannot have been the reason for the different start-up characteristic.

I can only speculate: The first operation of this emitter has modified the glue, or the thermal stress from the first operation has loosened the thermal contact of the heater to the ceramics and/or the reservoir a little bit, resulting in a faster heating.

By setting the start-up temperature to a higher value we could compensate for this, but at the expense of risking an overshoot of the thermal control after the start-up (in the transition to normal temperature). Remember that on Equator-S once the power to the heater dropped almost completely just after the start-up, causing the emission to cease.

Analysis of the start-up sequence
Our first assessment of the behaviour is confirmed. The detection condition for ignition is fixed to
Iion > 2.3 uA (or 12 in raw data). Iion is sampled every 0.52 seconds. After ignition the software switches the supply into constant current mode and switches the set value to the value for the current. These two actions occur within microseconds. Since the total current was set to 12.5 uA, the hv increased according to the characteristics of the source.

After having been 20 seconds above the threshold voltage, the automatic cleaning set in, with a set value of 50 uA total current over 20 seconds. During cleaning (and only during cleaning), the software limit of 9 kV is active. Since the hv supply is in the current mode the DPU detects the exceeding and starts to reduce the current setting of the supply. Unfortunately this reduction is programmed at a constant speed of 1 digit of the current set value per second (=0.4 uA/sec),
which in our case is too slow.

After the 20 seconds of cleaning the software measures the voltage for another 20 seconds to find out that it is still too high, and then goes into standby mode. The cleaning did not help to reduce the voltage. The reading of 7 kV is already within the falling slope of the shutdown.

Other options for cleaning - No options for this: The software limit of 9 kV is only valid during cleaning, and with the restriction of the slow control.

Operation Options:
a) Threshold checking active & cleaning enabled: This was the setting we had. It results in 20+20+20 seconds of HV > threshold, followed by standby.

b) Threshold checking active & cleaning disabled: This results in 20 seconds of HV > threshold, followed by standby.

c) Threshold checking inactive & cleaning in any mode: This results in permanent unlimited HV.
Recommendation for next operations:

Module A:
Since this reset has never been observed before and especially there is no proof that this can occur in an otherwise safe system, I recommend not to operate this module before the other one is completely finished.

Module B, heating:
I propose a moderate increase of both the startup and operating temperature to about 320 deg.

Module B, high voltage:
I propose to reduce the set value of the total current to the lowest value wich which an emitter will safely (without oscillatioons) start, taking into account that the beam current can be much smaller
than the total current.

The second proposal is to disable the automatic cleaning, to reduce the maximum time of high voltage to 20 seconds.

In theory a start-up directly into constant ion current mode would make the optimum setting independent of the efficiency, but at the expense of some fluctuations of the current and voltage.
Furthermore, we have clearly less experience with this way of start-up."

The recommended procedure described above will be followed on this module during operations for the time being.

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