BEXUS Student Experiment Documentation

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Abstract

The Earth's stratosphere contains aerosols of various origins, including aerosols of volcanic, cosmic and anthropogenic sources. Such aerosols are relevant to the climate. An experiment was flown on a stratospheric balloon, launched from Esrange, Sweden on October 8, 2008, as part of the BEXUS 7 campaign. It consisted of a pump creating an airflow through a filter capable of catching particles down to $0.3\mu m$ in diameter. A ground-controlled system of tubes and valves ensured airflow through the filter at an altitude of 12 km and above, up to the balloon floating altitude of 27 km. Upon landing, the filter was recovered and analysed using electron microscopy, autoradiography and X-ray fluorescence. Autoradiography and X-ray fluorescence indicated, with good significance, the presence of Co-57, In-11, I-125, Xe-133/Ba-133, Cs-137 and Ir-192.

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1 Introduction

Balloon flight campaigns provide a valuable platform for a wide variety of scientific disciplines, such as atmospheric science, space science, and others. BEXUS is an ESA-led German-Swedish campaign launching balloons in the stratosphere, allowing for in-situ measurements of this atmospheric layer. More information about BEXUS can be found at:

`http://www.rexus-bexus.net`

The stratosphere is the layer in the atmosphere between the troposphere and the mesosphere, at an altitude of approximately 10 km to 50 km.

Key information on stratospheric chemistry can be obtained by analysing the aerosols floating in it. Those aerosols are primarily of volcanic origin, but there are also anthropogenic aerosols and even some spaceborne ones. Such aerosols play a role in the atmospheric radiation balance and influence the world climate. Various methods have been used in the past to research stratospheric aerosols, but the method of using a filter and investigating this upon recovery is new.

1.1 History

On 19 November 2007, ESA announced the "opportunity for student experiments to be flown on two sounding rockets and one stratospheric balloon, to be launched from Kiruna in Northern Sweden". The deadline for application was 7 January 2008, and on this date the Stratospheric Census team (then consisting of four members; Mark Fittock was to join later) applied to ESA Education. On 30 January, the team received an invitation to present the project at the Selection Workshop at ESTEC, Noordwijk, The Netherlands, on 5-6 March. On 10 March, the team received confirmation that its experiment was conditionally accepted for flight. After the acceptance, team member Mark Fittock, a mechanical engineer, joined Stratospheric Census. A Preliminary Design Review (PDR) was held during the Training Week at Esrange, 21-25 April. In subsequent months, the team built on the experiment. The Launch Campaign was held 4-11 October, with Stratospheric Census launched on BEXUS 7 at October 8, 2008.

1.2 Overview

This document provides comprehensive and detailed information about the experiment design. The latest version can be found at the experiment website:

http://www.stratospheric-census.org

1.3 Acknowledgements and sponsors

The team would like to thank many different people, organisations and companies for various ways of supporting Stratospheric Census. The Department of Space Science, IRV, has provided financial support and provided resources for the team to use. The IRV staff, particularly Alf Wikström and Kjell Lundin, have spent considerable time and effort with the team's experiment. The team thanks the European Space Agency (ESA) and DLR for providing the opportunity to fly the experiment on a stratospheric balloon, and the personnel at Esrange for making this possible. Helen Page and her team and Olle Persson and his team have spent considerable effort in organising the selection workshop and the training week, the design reviews and the launch campaign. The team would also like to thank IRV's neighbours at the Swedish Institute of Space Physics, IRF, for the opportunity to use resources available there, such as a thermal testing chamber. The team thanks M. Khaplanov (MISU), P. Vögler (IRF) and K. H. Fricke (University of Bonn) for making available Lidar data to the team and giving an introduction to Lidar. All members of the review panels are thanked for their valuable advice. The team would like to thank Eurolaunch, the Swedish National Space Board for their parts in making the BEXUS project possible. Specifically, the team would like to support Progressum for the financial support, Elmarco for providing the filter and Chip45 for providing the microcontroller. The Czech Technical University (CTU) Institute of Experimental and Applied Physics (IEAP) is thanked for logistical and considerable financial support for performing the analysis, and the team thanks Dr. Vladimir Linhart for time spent on the analysis. Finally, the team thanks students Tommi Juopperi and Pooja Mahapatra. Tommi has helped with the electronics design and Pooja has assisted with various tasks.

2 Experiment description

2.1 Summary

Stratospheric aerosols are obtained by using a pump (section (8.6)) to maintain an airflow through a filter (8.7) during a balloon flight. Valves (8.1) open the system when the balloon reaches the stratosphere and close before the balloon descends. A ground station (12) is used to control the experiment but it can also operate in autonomous mode if the connection fails. Sensor data is downloaded from the balloon, indicating the status of the experiment.

After the flight, the received filter is extracted and analysed (10.5).

A photograph of the experiment on the BEXUS 7 gondola can be seen in figure (1).

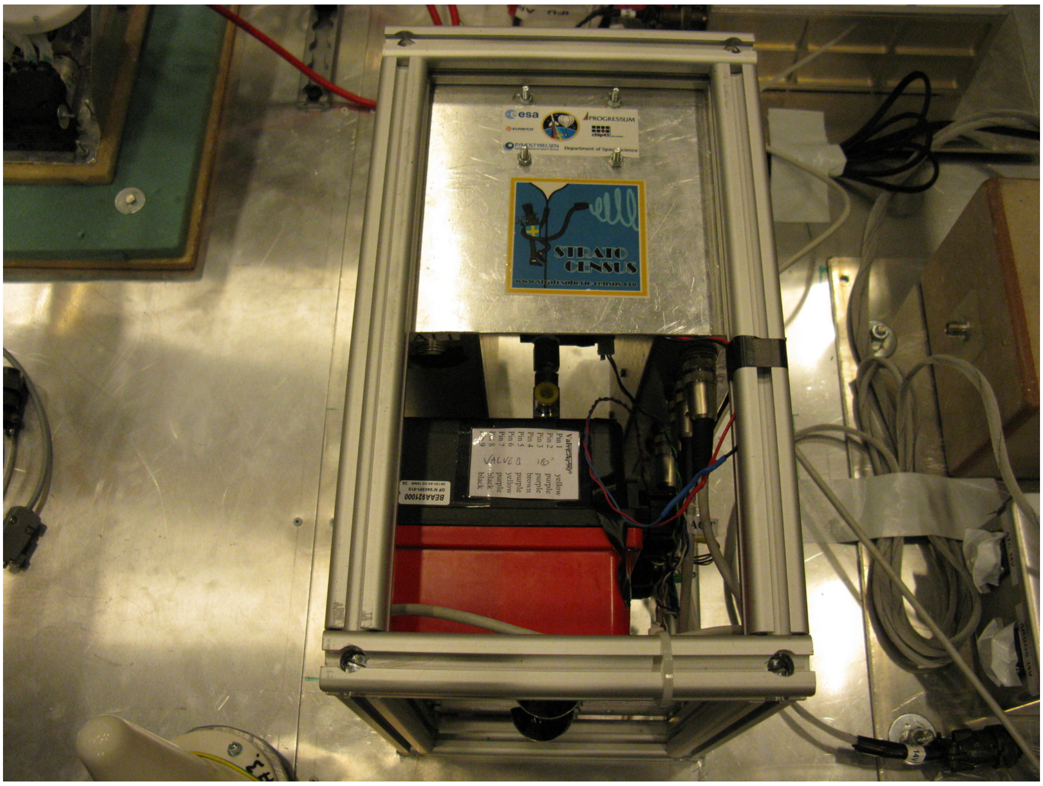

Figure 1: The Stratospheric Census experiment mounted on the BEXUS 7 gondola at “The Cathedral”, Esrange, Kiruna.

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2.2 Hardware

The core of the hardware are the pump the filter. This is supported by the structure and the electronics.

For the pump, Stratospheric Census uses the N 89 KNDC by KNF Neuberger, a choice motivated in section (8.6). The filter uses Nanospider ™ Technology, developed by Liberec Technical University (Czech Republic) and manufactured by Elmarco. See section (8.7) for a motivation of this choice.

The PCB board and the mechanical structure have been developed by the team. All other components are commercially available.

A list of components can be found the table in appendix (D). This list includes components that were acquired (mostly bought) by Stratospheric Census. It does not include components that were borrowed, such as the military connectors and the ground station hardware. A spreadsheet with the same information is available from the Stratospheric Census website at:

`http://www.stratospheric-census.org`

Part I
Scientific results

3 Scientific analysis

The stratosphere is the atmospheric layer extending from the tropopause to the stratopause. It is roughly the area where temperature increases with altitude. The composition is very similar to that of the troposphere, except that the stratosphere is very dry.

Stratospheric aerosols are important for understanding the chemistry of the atmosphere and have been a research focus for scientists for decades. This research has been either remote sensing or in-situ direct measurements of aerosols. Remote sensing detection of stratospheric aerosols can be done from ground-based or spaceborne instruments. Several techniques exist for in-situ measurements. On a balloon, one can use a nuclei-counting instrument. On aircraft, one can use impact surfaces to determine particle properties.

3.1 Scientific objectives

The key mission objectives of Stratospheric Census were:

- To design and develop a simple yet powerful concept of collecting aerosols in the stratosphere.
- To collect stratospheric aerosols using a filter and to recover the filter sample.
- To use different techniques of analysis (in particular neutron activation analysis and electron microscopy) for assessing the relative frequency of elements in stratospheric dust in the northern hemisphere subpolar region.

In addition to the scientific objectives, Stratospheric Census has the educational objective to gain, as students, knowledge and experience.

3.2 Stratospheric aerosols

The first major study into stratospheric dust (also known as stratospheric aerosols) appears to have been published in 1960 by Junge et. al [13]. In this study, an Aitken nuclei counter was used with a pressurised chamber to determine the concentration, size distribution and chemical composition of stratospheric aerosols. A detailed description can be found in the cited paper. The particle concentration at an altitude of 20 to 30km was measured to be less than 1 particle per cubic centimetre for particles smaller and larger than $0.1\mu m$ in radius, with limited quantitative results on the size distribution, though particles smaller than $0.01\mu m$ were found to have short lifetimes and particles larger than $1.0\mu m$ were found to be rare. Most particles were between $0.1\mu m$ and $1.0\mu m$. Chemical analysis showed a large amount of sulphur, particularly for particles between $0.1\mu m$ and $1.0\mu m$ in diameter. A small amount of silicon and iron was also detected.

Elterman et. al used ground-based optical measurements to determine features on tropospheric and stratospheric dust [6].

A comprehensive study was published in 1975 by Rosen, Hofmann and others, focusing on the global ([22]) and seasonal ([10]) dependence as well as size distribution ([21]) and sources ([9]) of dust concentrations using a large number of balloon measurements and a dedicated detector (described in [10]) for particles with a diameter $\geq 0.3\mu m$. Measurements above Barrow, Alaska, United States (71°N) in November 1973 show a mixing ratio of around 6particles/mg air at an altitude of 20km [22]. At “Ice island”, at 85°N, a concentration of around 1cm^{-3} was found at the same altitude. Higher altitudes were not measured in this report at those latitudes.

Size distributions are given in [21]. The size distribution is almost constant with altitude. A best fit function to the size distribution between 18 and 20 km altitude based partially on measurements by [21] is given in the same paper:

$$N_1(>r) = \frac{N_0}{\sqrt{2\pi}\ln(\sigma_g)} \int_r^\infty \exp\left[-\left(\frac{\ln(\frac{r'}{r_g})}{\sqrt{2}\ln(\sigma_g)}\right)^2\right] \frac{1}{r'} dr' \qquad (1)$$

In equation (1), $N_0 = 10cm^{-3}$, $\sigma_g = 1.86$, $r_g = 0.0725\mu m$. Refer to [21] for a discussion of this equation. One of the lines in figure (2) is a graphical representation of this.

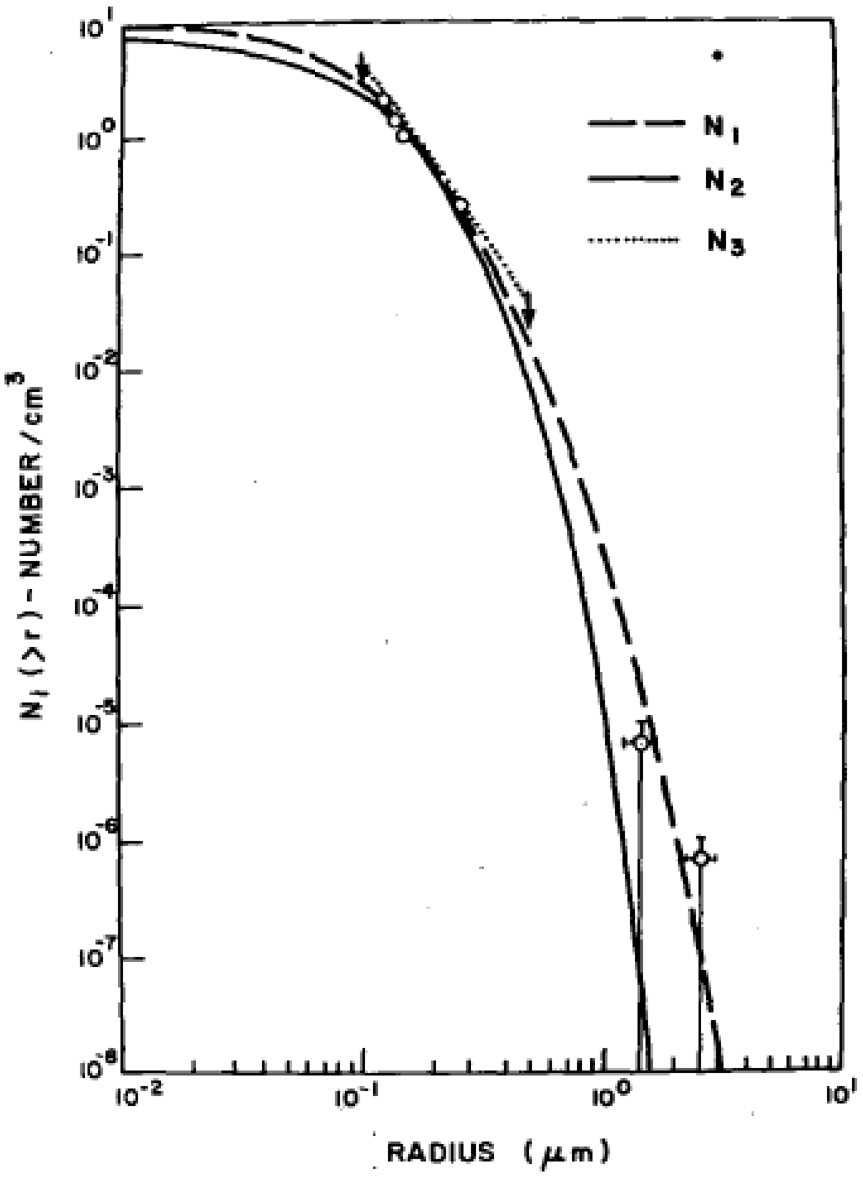

FIG. 3. Integral particle concentration versus particle radius measured by photoelectric particle counter for the 1971–74 period. The data are approximated by log-normal (N_1), exponential (N_2), and restricted power law (N_3) size distribution functions.

Figure 2: Size distribution of stratospheric particles at an altitude of 18 to 20 km. Source: [21]

In [9] is reported that the concentration of sulphur above the tropopause is between 0.1 and 0.3 ppbm (parts per billion mass).

Smaller particles exist but are not considered in this project, as they can not be detected by Stratospheric Census.

3.2.1 Composition

Under normal stratospheric circumstances, the bulk of aerosols can be approximated by droplets of 75% H_2SO_4 and 25% H_2O [17]. Volcanic eruptions increase the amount of dust considerably, but the profile is still mainly sulphur, since this is the origin under normal stratospheric circumstances as well.

Key issues in estimating the amount of cometary dust one might expect to find in the stratosphere are the survival upon atmospheric entry and the duration in the stratosphere. Particles that are big enough to survive the atmospheric heating are known as meteorites, fall straight through the stratosphere down to Earth, and are many orders of magnitude larger than what the team is studying. The chance of collecting a meteorite is rather small. Particles that are small enough to circularise their orbits and then survive heating and mechanical stress while descending to around 40 km altitude are smaller than $100\mu m$ [3].

The flux of $10\mu m$ particles is around $1\text{m}^{-2}\text{day}^{-1}$, and their density is around $3 \cdot 10^{-4} m^{-3}$. Particles smaller than $2\mu m$ are hard to detect as such, because the total mass is much smaller than the total mass of submicron sulfate aerosols. However, the elements are quite different from those of volcanic origin, and are thus quite possible to detect if any particles have been collected at all, such as iron, nickel, calcium, aluminium, titanium, magnesium. [3]. The composition and form of those depends on the size of the particles, and the exact likelihood to encounter those varies.

3.3 Platform constraints

The scientific possibilities are limited by engineering and platform constraints. The engineering constraints (discussed elsewhere in the document) are also limited by platform constraints. Platform constraints are determined by such questions as:

- How long will the flight take?
- What is the geographical extent of the flight?
- What altitude will the balloon reach?

- What are the environmental conditions within the balloon gondola?
- What are the constraints imposed upon the experiment by the gondola bus and the other experiments on the gondola?

Those questions are considered throughout the rest of the document, starting with the geographical constraints in the next subsection.

3.4 Location-specific considerations

3.4.1 Geography and climate

Esrange is located in the municipality of Kiruna, Norrbotten county, in Swedish Lappland, at 67 53' 38" (67.8938) N, 21 6' 25" (21.10694) E at an altitude of approximately 300m. This region has a subarctic climate (*DfC* in the Köppen classification system). In the heart of winter, the ground temperature is usually around −15°C but temperatures as low as −48°C have been recorded. Precipitation is relatively low year round.

3.4.2 Balloon trajectory

Winds at an altitude of 30km are generally westerly between September and April and speeds are maximal around January-February. The maximum wind velocity that has been observed is $380\frac{\text{km}}{\text{hour}}$ at 10 February 1974. The winds start slowing down early March and turn around by the end of April. During this time, the wind direction is unstable. The flight time during January-February might be as low as $1-2$ hours [4]. In April and September, flight times of $5-10$ hours are likely. Much longer flights are possible, but for political reasons the balloon will descend before flying into Russia. The temperature in the stratosphere at 30km is about $-60°C$ [1].

4 Analysis of Nanofilter

This section discusses all details concerning the nanofilter sample used during the flight of the Stratospheric Census experiment. A single filter batch (containing 10 pieces) cut from one raw sheet of filter material was provided by Elmarco. These filters were used as:

- Control and testing samples (9 pieces): The analysis procedure had to be established and control samples were employed to subtract background and possible contamination.
- Flight sample (1 piece): This filter was used to collect dust in the stratosphere.

4.1 Details on filter extraction and transport

The filter extraction and transport was carried out by Jaroslav Urbář and Mark Fittock. The following was done in parallel with control samples to expose them to the same conditions.

- In a clean environment at IRV: Dismounting the Stratospheric Census experiment tubing, putting the whole filter mounting (exactly as acquired from Elmarco) into the cleanbag, as suggested by Dr. Vobecky to get the same initial samples. Another reason is that due to the delicate structure of the nanofilter layer, the whole filter was shipped unseparated (i.e. the nanolayer on its cellulose substrate).
- The filters were inserted into multiple double-sealed thin PE bags, cleaned by distilled water.
- Separate cleanbags with flown/control filters were packed into a safety transport envelope at IRV.
- The samples in a safety transport envelope were carried to IEAP by Jaroslav Urbář .

4.2 Physical and nuclear sample diagnostic methods

4.2.1 Spectra from the original VR-1 irradiation

Spectra were taken from a 2h-long gamma-spectroscopy acquisition and a 1h-long irradiation at the educational test reactor VR-1. These were preliminary measurements to establish the analysis concept: Due to the very low fluxes used by the test reactor (fluence of 10 thermal neutrons per square meter; equivalent flux around $3 \cdot 10^8$neutrons$/m^2s$), negligible detection results were obtained even aften an exposure time of one hour.

The following observations could therefore be made:

- The spectrometer is by no way saturated from acquiring the spectra from the activated sample – not from the filters own composition (organic PA6 and cellulosis considering the substrate as well) specifically C, N, O – these elements have low activation cross-section for thermal neutrons, making it a suitable substrate for samples.

- The filter by itself can withstand the thermal conditions present in the LVR-15 reactor, as was checked after the analysis (in the PE irradiation foil, up to 80°C)

4.2.2 Sample foil preparation

- After the delivery of the filters, at IEAP (CERN-certified cleanroom for preparing of Si-tracking detectors) they were dismounted from the filter holding ring and inserted into the irradiation sample foils (using a carbon pinzette). The filter samples were inserted into PE foils of 0.2mm for routine INAA analyses. Additionally, the foils were cleaned with HNO_4 and washed in ultracleaned distilled water, with extracted otherwise normal silicon contaminant.

- Hot-air autogene was be used for complete foil edge closures.

- Normal etalons for elements of interest (Au, Cd, Co, Eu, Na) for comparison.

4.2.3 Autoradiography analysis (preceding INAA)

The team proceeded with analyses and finished the setup of the X-ray fluorescence analysis apparatus (geometric configuration). Using the Am-241 source the fluorescence emission lines up to 60keV can be observed. HPGe spectrometry detected spectra of natural emittors in the sample (measurements always took over 1 day for statistically significant results).

- Four-fold energetic calibration ratio, spectra of 152Eu, 22Na, 60Co and 511keV annihilation peak.

- Isotopes located: Co-57, In-111, I-125, Xe-133, Cs-137, Ir-192 And others with low significance level ($<$ 1 FWHM).

Figure 3: Autoradiography analysis equipment

```
1) Eu-152 calibration Tacq=600s  40.45 kBq (T1/2=4858 days)  (w/o .CNF)
(live-time Background Subtraction Normalization Coefficient 0.00223184)
2) Na-22 calibration   Tacq=600s  102.8 kBq (T1/2=950 days)
(live-time Background Subtraction Normalization Coefficient 0.00223184)
3) Co-60 calibration   Tacq=600s  204.3 kBq (T1/2=1925.4 days)
(live-time Background Subtraction Normalization Coefficient 0.00223184)
4) background measurement (268836s live time)
5) volc. layer sample cross-check acquisition (148893.9s)
(live-time Background Subtraction Normalization Coefficient 0.5538466)
6) final flight sample (84873,4 s)
(live-time Background Subtraction Normalization Coefficient 0.319855)
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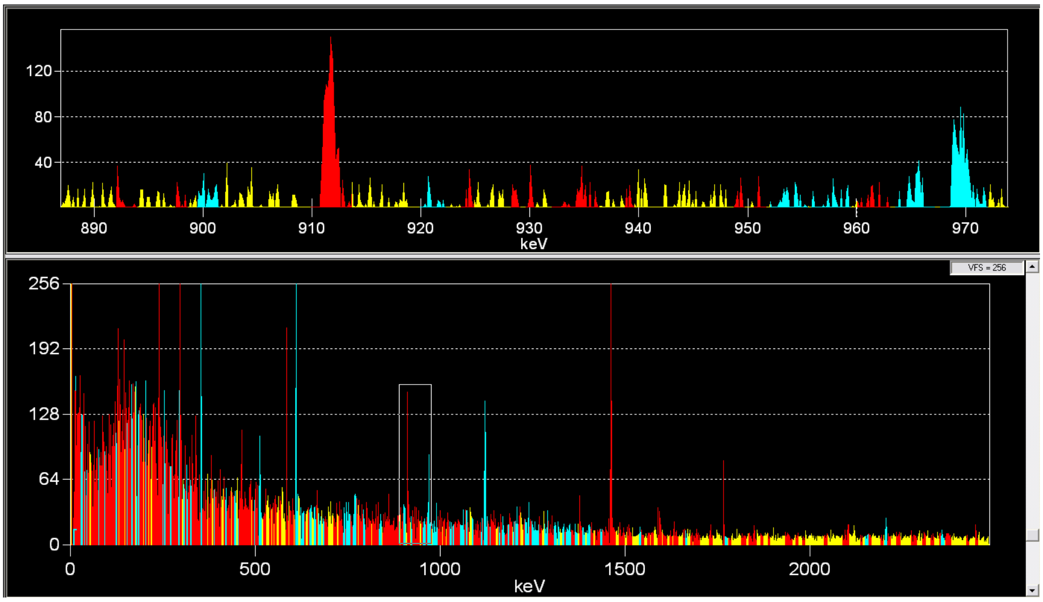


Figure 4: Spectral lines of stratospheric flight sample as recorded by autoradiography.

4.2.4 X-ray fluorescence analysis

Non-destructive analysis with strong X-ray emitter used (241Am, 740MBq) to excite samples. Therefore we can see characteristic radiation spectral lines ONLY below 60keV. Energetic calibration with: Am, Co, Cd, Au Flight sample acquisition, background acquisitions: $\approx$ 14 hours

Steps carried out:

1. Calibration with radionuclide source applicable for further analysis: Am-241 (477kBq) (Later a strong X-ray fluorescence source with 740MBq was used.)
   1200s=20min.
   (live-time Background Subtraction Normalization Coefficient 0.38936)
   IMPORTANT LINE: 59.5371 keV with associated Gammas - 26.345, 33.195, 43.423 keV

2. Au sample calibrationration (conducting plate for strip detector used)
   1800s=30min.
   (live-time Background Subtraction Normalization Coefficient 0.58404)

3. Cd sample calibration
   1800s=30min.

(live-time Background Subtraction Normalization Coefficient 0.58404)

4. Cd sample calibration
   1800s=30min.
   (live-time Background Subtraction Normalization Coefficient 0.58404)

5. Co sample calibration
   1800s=30min.
   (live-time Background Subtraction Normalization Coefficient 0.58404)

6. flight sample with steel ring acquisition
   5637s

7. flight sample extracted - important measurement
   50146s
   (live-time Background Subtraction Normalization Coefficient 16.2706)

8. X-ray background in acquisition configuration. 3082s

Peak	ROI Start	ROI End	Peak Centroid	Energy (keV)	Net Peak Area	Net Area Uncert.	Continuum Counts	Tentative Nuclide
1	732-	758	745.31	23.57	3.60E+002	83.56	1.59E+003	In-111
2	768-	795	781.53	24.73	2.41E+003	155.77	1.62E+003	.....
3	867-	894	880.60	27.90	3.52E+002	77.19	1.48E+003	I-125,I-123
4	886-	913	899.99	28.52	1.64E+002	73.11	1.45E+003	U-233,Np-237
5	978-	1005	992.18	31.47	3.21E+002	84.77	1.33E+003	Ba-133, Xe-133, Cs 137
6	997-	1024	1010.91	32.07	1.55E+002	86.80	1.30E+003	.....
7	1015-	1042	1028.67	32.64	2.06E+002	88.27	1.28E+003	.....
8	1036-	1063	1050.48	33.34	2.45E+002	77.87	1.25E+003	Am-241, Cs 137

4.3 Summary of Results

Precise calibration, background subtraction, followed by multiple analysis techniques led to the conclusion that both autoradiography and X-ray fluorescence analysis provide, with good significance, the presence of mainly:

- Co-57
- In-111
- I-125
- Xe-133/Ba-133

- Cs-137
- Ir-192 of possible extraterrestrial origin

4.4 Electron microscope imaging test results

Preliminary Electron microscopy images are shown in figure (5). The analysis serves to determine the amount of collected dust and is the final method in the analysis chain. Results will be made available as soon as possible.

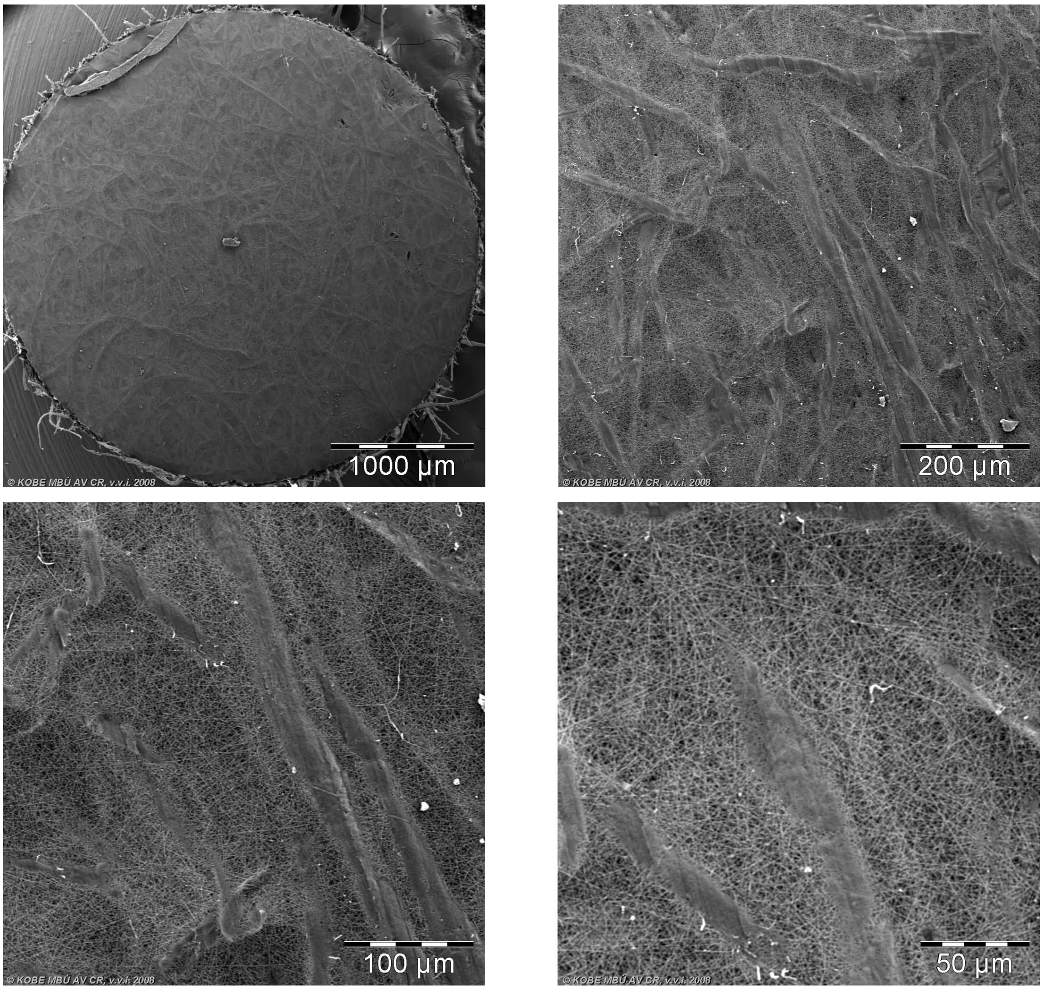


Figure 5: Nanofilter layer on its cellulose substrate taken by electron microscopy at various resolutions

4.5 Irradiation using the research reactor LVR-15

An irradiation slot is reserved in the first weeks of January 2009, immediately after the reactor startup becomes available. Activation is done with vertical irradiation channels with a pneumatic rabbit system for short-time irradiation. All irradiations and analyses will be done in parallel with the control filter sample to find the contribution from the stratospheric flight. Custom positioning of filter samples for reaching the optimal dose, from lower limit, thresholded by VR-1 reactor 1h activation. Exposure at LVR-15 of 3-5 mins expected. While thermal conditions in irradiation channels might get too high for the cellulose substrate, a CHOUCA irradiation rig will be used. It enables full temperature control of irradiated specimen Previous testing using low-flux neutron activation analysis has proven:

- The spectrometer is by no way saturated acquiring spectra from the activated sample – not from the filters own composition (organic PA6 and cellulosis considering the substrate as well) specifically C, N, O – these elements have low activation cross-section for thermal neutrons, making it suitable substrate for samples.

- The filter can withstand the thermal conditions present in the LVR-15 reactor, as was checked after the analysis (in the PE irradiation foil, up to 80°C)

The detection limit of elements specifically at LVR-15 when using ICP-MS are shown in table (1), for ELAN 6000 (Perkin-Elmer).

Element	$\mu g/l$	Element	$\mu g/l$
Al	0.006	Sn	0.002
As	0.006	Ta	0.0008
B	0.09	Th	¡0.0005
Bi	0.0005	U	¡0.0005
Cd	0.003	V	0.002
Co	0.0009	W	0.001 ***
Cr	0.02	Y	0.0009 !!!
Fe	0.4	Zn	0.003 !!!
Hf	0.0006	Zr	0.004
In	¡0.0005	Ce	0.0004
Ir	0.0006	Dy	0.001 ***
La	0.0005	Er	0.0008
Mn	0.002	Eu	0.0007
Mo	0.003	Gd	0.002
Nb	0.0009	Ho	¡0.0005
Ni	0.005	Lu	¡0.0005 ***
Pb	0.001	Nd	0.002
Pt	0.002	Pr	¡0.0005
Re	0.0006	Sm	0.001
Ru	0.002	Tb	¡0.0005
Sb	0.001	Tm	¡0.0005
Sc	0.02	Yb	0.001
Si	0.06		

Table 1: Detection limits for elements using ICP-MS: ELAN 6000 (Perkin-Elmer) after optimal irradiation at LVR-15. Elements of high interest and good detectability are marked ***, those with complicated resolution are marked !!!.

Part II
Flight report

5 Pre-launch

The Stratospheric Census experiment was delivered to Esrange (launch site) the first time on October 2nd, 2008 for tests with the E-Link communication system. These tests were carried out successfully.

The days between October 3rd and October 8th (launch date) were filled with preparation (integration of experiment on the balloon gondola, integration of nanofilter into the experiment) and waiting for favourable weather conditions. The following tests were carried out:

- Electromagnetic Interference Test
- E-Link Test
- Long-term test of 'Autonomous Mode' (a functional mode that would have allowed the experiment to work even in case of a up- and/or downlink failure)

The team was also in contact with the Lidar operation personnel and obtained valuable information about the dust concentration in different atmospheric layers during the campaign week (see section (5.1.1)). For the flight day, a pre-flight procedure was defined.

5.1 Scientific considerations

5.1.1 Lidar

During the campaign week, a lidar located at Esrange was operated by a team by K. H. Fricke from the University of Bonn. [1] A lidar is a remote sensing instrument sending a laser pulse into the atmosphere and measuring the strength and the polarisation of the backscattered echo. From lidar measurements, information on molecules and aerosols can be obtained. The backscatter ratio gives information on the concentration of scatterers, and the polarisation of the backscattered signal gives information on the nature of aerosols (liquid or solid).

Measurements done by the lidar team are presented in figures (6) and (7).

[1] Thanks go to M. Khaplanov (MISU), P. Vögler (IRF) and K. H. Fricke (U. Bonn) for the lidar data and information.

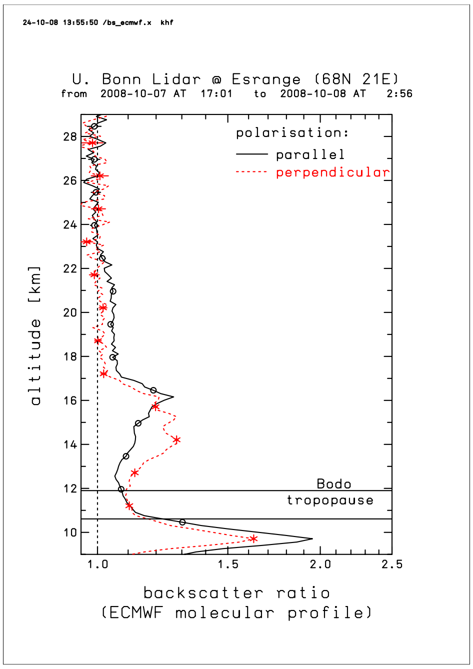


Figure 6: Lidar measurements at Esrange from 7 October 17:01 to 8 October 2:56. See text for a discussion.

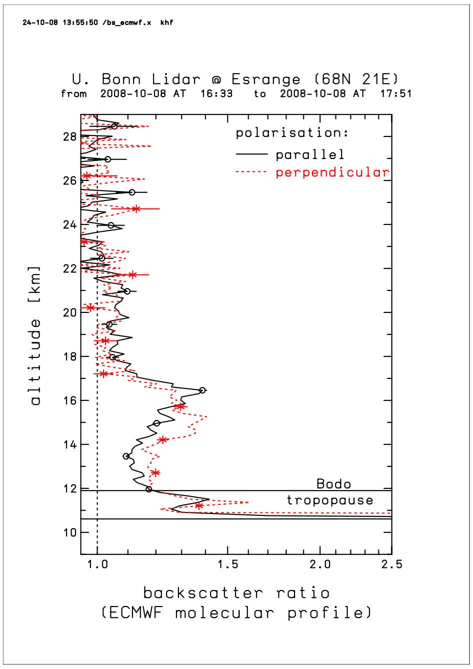


Figure 7: Lidar measurements at Esrange from 8 October 16:33 to 8 October 17:51. See text for a discussion.

In figures (6) and (7), it can be seen that there is considerable backscatter between 12 and 18 km. It can also be seen that there is some depolarisation; depolarisation is caused by particles that are not spherical, and particles that are not spherical are not liquid and must be solid.

On 7 August 2008, an eruption occurred at the Kasatochi volcano of the Andreanof Islands subgroup of the Aleutian Islands, Alaska, USA. The lidar team believes that the aerosols in the 12-18 km layer stem from this volcano. For this reason, the Stratospheric Census team decided to open the valves as soon as the balloon had risen through the tropopause.

6 Launch day & flight

The Esrange personnel decided to try for a launch of the BEXUS-7 balloon on Wednesday, October 8th, right after the launch of the somewhat smaller BEXUS-6. The following sections discuss key events of flight operation, a complete chronological account with all commands given is available in section 6.6.

6.1 Last minute E-Link test and payload take-out

On launch day, October 8th, at 13:02 CET, the experiment, fully integrated on the gondola, was powered-up for a last E-Link test. This test was carried out successfully. Since the E-Link system was then switched off again by Esrange (due to moving the gondola), the experiment had to be powered down again. (Otherwise, the experiment would have switched to 'Autonomous Mode' after one hour, starting the pump and opening the tube system.)

Subsequently, the BEXUS-7 gondola was moved onto the launch pad at 13:36 CET.

6.2 Plug-removal and pump power-on

To protect the in- and outlets of the experiment's tubing system, a yellow and blue plug were used as seals prior to launch. These plugs were removed and returned to the ground station at 14:45.

In order to avoid switching on a cold pump in the stratosphere, the team had decided to let the pump run during ascent, at a low voltage rating. This switch-on was carried out at 14:32 (PUMP 180).

At this stage, Stratospheric Census was go for launch!

6.3 Launch and flight

The BEXUS-7 gondola with the Stratospheric Census payload was launched on October 8th at 15:36 CET. Figure 8 shows the altitude profile of the flight from take-off to landing.

Figure 8: Flight trajectory, with color-coded altitude

Prior to launch, the team had decided that the actual experiment was to be started at an altitude of $11 - 12\,km$ altitude, where, based on Lidar information, volcanic dust could be expected. The experiment start procedure therefore was commenced at 16:07 after 32 minutes of flight. The following steps had to be taken:

1. Switch the pump the full power (PUMP 255, at 16:07)
2. Open valve A (GVOA, at 16:13)
3. Wait for the feedback information from valve A. After less than a minute, the status information showed that valve A had actually opened. The command for opening valve B was issued (GVOB).
4. Receive the information from valve B - at 16:16, also this valve was indicated to be open.
5. Cycle the pump several (3) times: Switching the pump on and off was deemed necessary due to testing results, when the pump needed several on-off cycles to actually start running.

Experiment start procedures were finalised at 16:17, just after the balloon had passed the 12 km mark.

6.4 Temperature monitoring and heater testing

The temperature of all experiment components was closely monitored during flight. It has to be emphasized that the experienced conditions were less harsh than anticipated and no thermal problems whatsoever were encountered. Refer to figure 9 for the complete temperature profile. (The time axis in this and all following figures starts with experiment power-on, 65 minutes before the actual launch.)

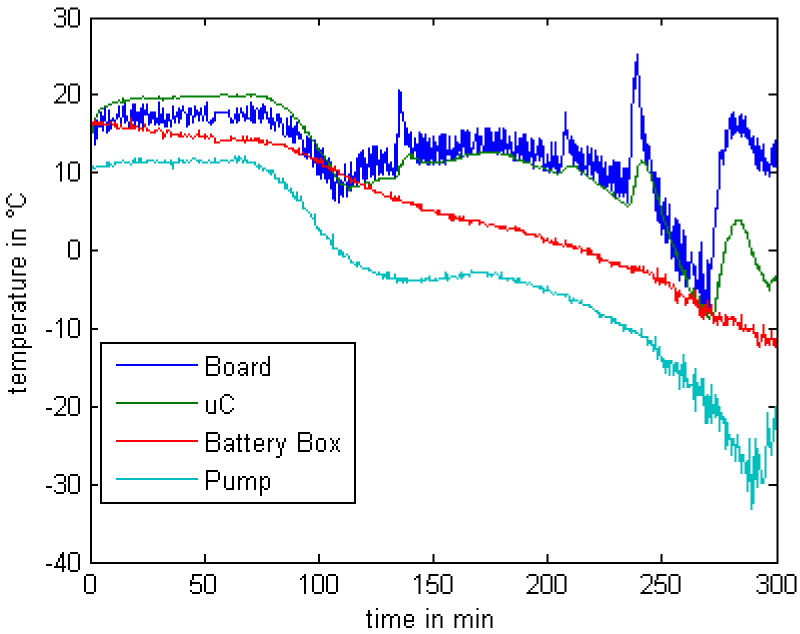


Figure 9: Temperature during flight

- uC (microcontroller) and PCB, both inside the electronics box, show the same temperature profile. The sensor on the PCB shows short time fluctuations (graph less smooth) which can be attributed to earlier problems encountered with this specific thermistor.
- The pump temperature was lowest throughout the flight, due to the fact that the sensor was mounted on the outer pump housing, in free air. A temperature surge during full power pump operation had been expected, but did not occur.

- uC and PCB temperature show spikes that are due to the heater being activated and tested by telecommand from the ground. The heater operation profile, matching the temperature profile, is shown in figure 10.

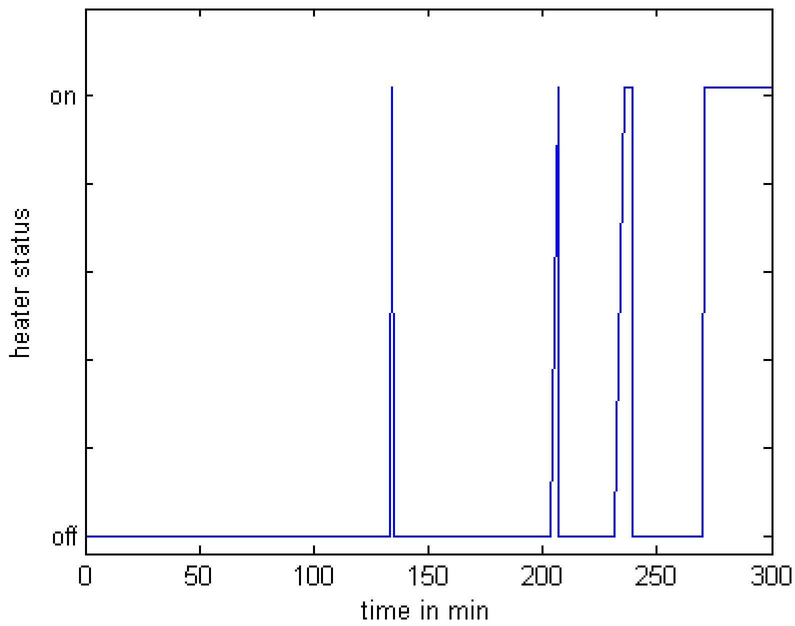


Figure 10: Heater status during flight

The heater was tested several times to ensure its proper functionality and to observe the reaction in terms of temperature. Towards the end of the flight, when night was approaching and environment temperatures fell, the heater was kept on to ensure that the experiment would stay alive as long as possible.

6.5 Experiment end and cut-down

A stratospheric balloon flight is terminated safely by cutting down the gondola and the following opening of a parachute. In order to end the dust-taking phase of Stratospheric Census without the time pressure of descent and a looming communication cut-off, the team had decided to stop the experiment and remotely seal off the filter in good time before cut-off.

This process was started at 18:30 by switching off the pump. At 18:31 valve A closed, on 18:33 valve B. Both valves moved at the first try, after being in open position under cold conditions. The procedure of stopping the experiment was therefore concluded successfully. This point marked a success for the whole team and its electrical, mechanical and software engineering. Figure 11 gives an overview about the flight trajectory, with the sample taking phase colored in blue.

Figure 11: Flight trajectory, with color-coded experiment status: Stand-by mode (green) and Sample mode (blue)

Accurate (time) information about when the valves were open is shown below (figure 12):

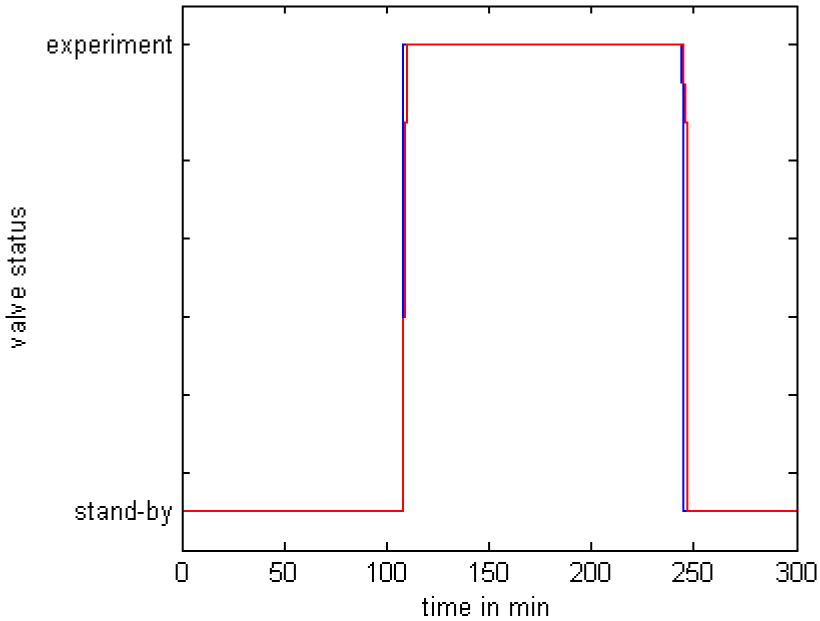


Figure 12: Valve status during flight

6.6 Complete flight operations

The following table gives a complete account of all flight operations (telecommand) and corresponding comments.

CET	T	Event/Comment
11:15	-3:45	preliminary count down, ground station setup complete
12:01	-	count down stopped
12:21	-3:09	count down restarted
13:02	-2:28	experiment powered up (batteries plugged in)
13:20	-	Last E-Link test successful
13:30	-	E-Link off, experiment powered down
13:36	-1:54	Payload take-out
14:31	-0:59	Power-up, connection stable. PUMP 255, STTO 28. OK from team.
14:32	-0:58	PUMP 180
14:45	-0:45	Blue and yellow plugs returned to ground station
15:36	**0:00**	Launch
15:42	+0:06	Altitude $\approx 2273\,m$
16:00	+0:24	Altitude $\approx 7500\,m$
16:08	+0:32	Altitude $\approx 9700\,m$
16:07	+0:33	Decision: Experiment start. PUMP 255
16:10	+0:36	Pump temp. $2°C$
16:12	+0:38	Pump temp. $0.3°C$. Altitude $\approx 11500\,m$
16:13	+0:39	GVOA
16:13	+0:39	Valve A open. GVOB
16:16	+0:42	Valve B open. PUMP 0. PUMP 255. (pump cycling 3 times)
16:17	+0:43	Altitude $\approx 13100\,m$
16:37	+1:03	Altitude $\approx 20000\,m$
16:39	+1:05	HEON. Board temp. $11°C$
16:40	+1:06	HEOF. Board temp. $18°C$
16:55	+1:19	Altitude $\approx 26000\,m$
17:00	+1:24	Floating altitude reached. Altitude $\approx 27000\,m$
17:21	+1:45	GSTTC 49
17:53	+2:17	HEON
17:54	+2:18	HEOF
18:21	+2:45	HEON
18:25	+2:49	HEOF
18:30	+2:54	PUMP 0. GVCA
18:31	+2:55	Valve A closed. GVCB
18:33	+2:57	Valve B closed
18:44	+3:08	GSTTO 255. GSTTC 255.
18:57	+3:21	HEON. (Cut-off happened around this time.)
19:28	+3:52	Loss of connection.

6.7 Postflight system performance analysis

6.7.1 Electromechanical

Both actuators worked neatly during the flight. Feedback of the status of the actuators was sensed by microswitches and sent back to ground. The pump was switched on on ground already and checked if it ran according to the set speed by inspection. No information can be given whether the pump worked during the flight. However, the pump was tested down to $-46\,^{\circ}\mathrm{C}$ without encountering any flaws. The pump temperature, however, was continiouly measured and was well within the tested temperature range, see the temperature diagram (figure 9).

6.7.2 Electronics

The electronics survived the lack of atmosphere and low temperatures at the same time. The heat generation of components inside the box together with the additional heater was sufficient to keep the temperature well within the operating ranges of all components.

6.7.3 Batteries

Batteries were overdesigned since a lower temperature during flight inside the battery box was expected which would have reduced the performance. Until cut-off, no temperature lower than $-7\,^{\circ}\mathrm{C}$ was measured in the battery box.

6.7.4 Thermal

The thermal design can be considered sufficiently accurate since no failures due to low temperature were encountered.

Part III
Experiment design

This section presents all details of the Stratospheric Census experiment design. Please consider that as such, it is a continuation and update of the information given in the CDR document.

7 Electronics

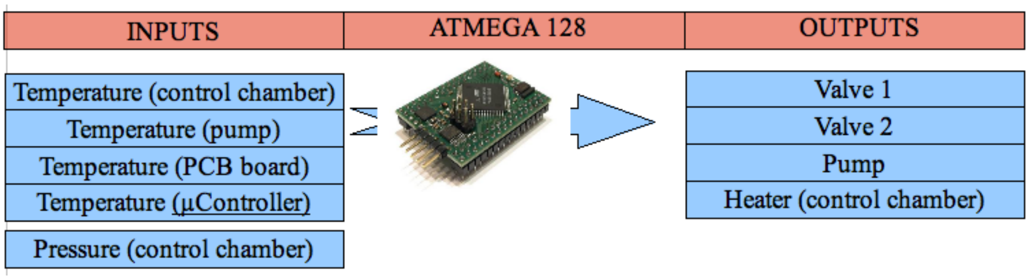


Figure 13: Schema for the information flow

The heart of the electronics control system forms an ATMEGA128 microcontroller on a Crumb128 board. It senses pressure and temperature from various points and makes decisions when to switch on the filtering unit. A logical schema can be seen in figure (13), a circuit diagram is in figure (22) on page (83) in appendix (A.1).

The electronics is placed in a box.

7.1 Temperature

The temperature is measured at four points: inside the control system, on the surface of the pump, and at two other points. This is done by means of a voltage divider formed by a thermistor and a 30k resistor. The resistance of the thermistor is calculated by the B-parameter equation.

$$R = R_0 e^{B(\frac{1}{T} - \frac{1}{T_0})}$$

For the Epcos thermistor [8] used by Stratospheric Census, $B = 3970$ at $T_0 = 300K$. In combination with the resistance it yields the curve as seen in figure (14). The voltage is fed into an analog input of the microcontroller.

The microcontroller is connected to the heating panel of the control unit and the heating clamp of the filtering unit via relays. These are switched on when the temperature drops below a certain temperature. The sensor on the surface of the pump is for safety reasons. It assures that the temperature of the pump is known at every time so that the operator can decide to switch off the pump in case it gets too warm.

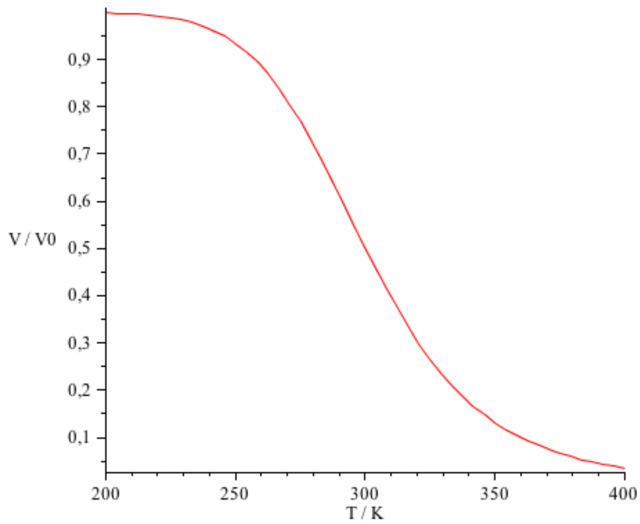


Figure 14: Voltage as a function of temperature for an Epcos thermistor.

7.2 Pressure

The pressure sensor is a critical part of the electronic subsystem. It determines the altitude and launches the filtering process. The sensor is from the ASDXD0 serios by Honeywell, which provides an absolute pressure range from 0 to 103 kPa. This sensor is placed inside the control unit. For correct operation, an outgassing hole is provided in the electronics box.

7.3 Filtering unit

The components of the filtering unit, i.e. the valves and the pump, are connected with power mosfets that can be switched on or off.

7.4 Downlink

The downlink is provided by Esrange via a system called E-link. The RS232 port of the microcontroller is connected with the E-link via a shielded twisted three wired cable. The crumb128 supplies a driver for RS232 communication. On the E-link side a MIL-C-26482 series I connector is used. The control box provides a circular socket for this interface (see section (11.5)). The connector is borrowed from Esrange for the flight.

7.5 Heating

To prevent freezing of the components through the outgassing hole heating resistors are soldered onto the PC board. If the temperature inside the control chamber drops below a certain threshold the resistor network is switched on by the corresponding MOSFET. Six resistors are put in parallel, each of them providing $(24\text{V})^2/680\Omega = 0.85\text{W}$ of heat.

7.6 Risk analysis

Please refer to section (11.1.1.1) for a safety analysis of the electronics subsystem.

8 Structure

The structure that supports all the experiments components is constructed from aluminium (see also section (8.5)). This material is chosen because it is light, stiff and easy to work with. This choice is also supported by the Department of Space Science (IRV) (where four out of five team members are located) as the institute has considerable stocks of aluminium plate and rod.

8.1 Pipe substructure

The pipe substructure of Stratospheric Census comprises of three lines connected to a pump.

The pump, described in section (8.6), has two BSPP 1/8" ports. Although this diameter is suitable for the system, finding suitable components that would connect directly proved difficult and for costs sake it was decided to use simple adaptors to switch to 1/8" NPT connections. By using this small diameter, there is greater risk of the filter being plugged by particles however, due to the low concentrations, this should not be a problem. By staying with this line diameter, there is also the added benefit of low weight.

All fittings are made of stainless steel.

As per the requirements of the pump [15], all loads are on the suction line. In order to run the pump at a low speed to avoid seizing, two inlets are available to the suction port of the pump that can be switched using a 3-way switching valve couple to an electric actuator.

The primary initial line begins with a simple valve as shown in figure (15). This valve's function is to stop contamination of the filter during the ascent and descent of the balloon to ensure that the dust collected is all stratospheric. The filter assembly is connected between this valve and valve B so that both valves and the filter can be removed to avoid contamination when removing the filter for analysis. This is connected by a short length of pipe that is used for any sensors necessary to monitor the flow to the pump (via an adaptor).

The collection intake line is a straight pipe from the exterior of the gondola so that the pump can draw a small quantity of air through the system. This is to allow the pump to operate at low speeds during the ascension of the balloon avoiding the possibility of seizure. The inclusion of a valve at this point is necessary in any case as it must be possible to isolate the filter for removal at the end of flight. The exhaust is simply released into the gondola's interior as it does not disturb Stratospheric Census' or other experimenters' apparatus.

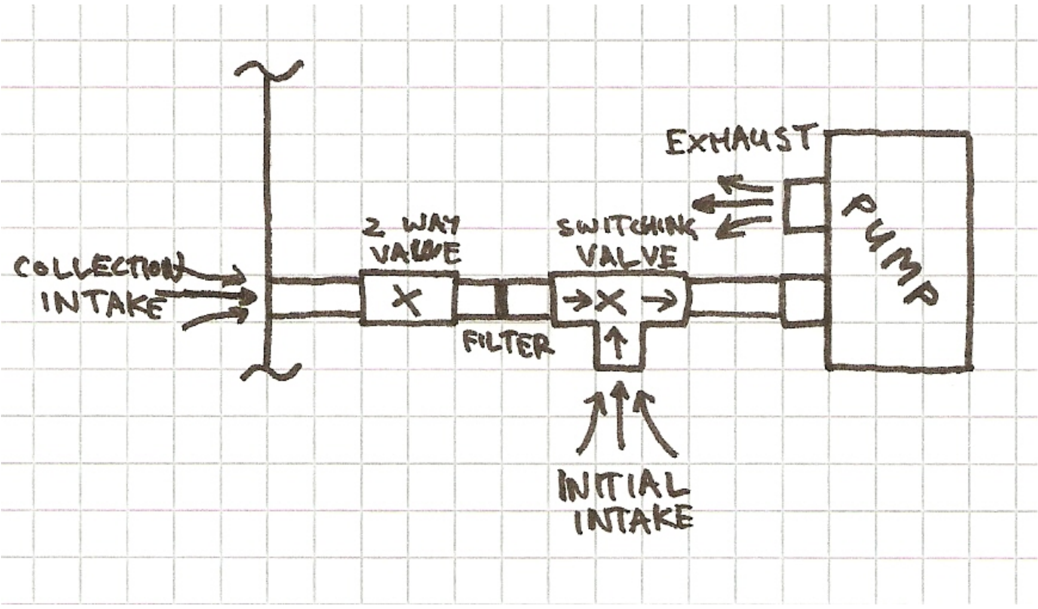


Figure 15: Sketch of the pipe.

Figure (16) shows the CAD design from various angles.

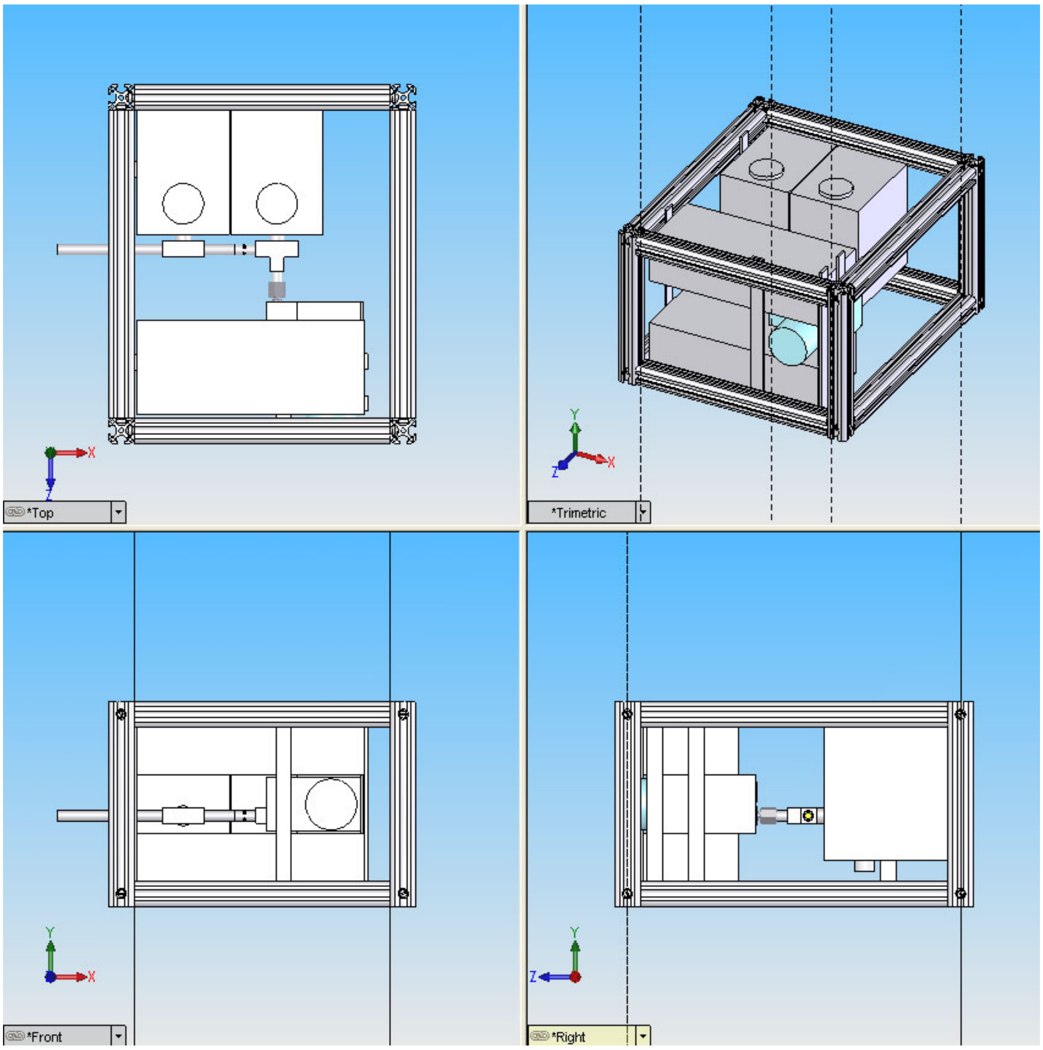


Figure 16: Structural design of the experiment.

8.2 Volume budget

The dimensions of Stratospheric Census are 300mm * 350mm * 200mm

The length of 350mm is found by using the total length (for correct orientation and taking into account the threads) of the components required for the primary intake line.

The height requirement of 300mm is dictated by the actuators, valve B and the elbow used.

The 200mm width is to allow space not only for the pipe and pump subsystems, which require approximately 100mm, but also for the control and battery boxes. This has been given considerable space so that the batteries can be securely attached and to minimise risk of damage to the PCB.

8.3 Frame stress analysis

For the frame, some stress analysis was conducted. Firstly, the failure mode needed to be ascertained. For buckling calculations, a length of 300mm was used. The max force that could be withstood before buckling occurs was calculated using:

$$F_{buckle} = \frac{\pi^2 EI}{\nu^2} \qquad [N]$$

Where E is the Young's Modulus of the material, I is the second moment of inertia and l is the length. This gave a value of 110 kN for the max load before buckling due to the reasonably short length compared to profile ($I = .0143\,m^4$).

In order to find a critical loading limit, the plastic limit of the aluminium was found so that it could be compared with the buckling limit:

$$F_{plastic} = \sigma_{plastic} A_{cs} \qquad [N]$$

Where the cross sectional area was approximated from the density of aluminium and the weight of 1 metre of the bar. Using a plastic limit of 270 MPa for this bar as was selected by [11, page 17] the maximum load was found to be 69 kN.

Comparing this to a rough force estimate of 8 kN by using 10 kg at 10 g as defined by with a shock factor of 2 [14, page 280] and a safety factor of 4 [14, page 263] shows that the structure is able to withstand particularly brutal shocks caused by malfunctions of the balloon system. This is important where the sample collected during flight is particularly vital to the success of the flight.

8.4 Flow analysis

In order to verify that a pump selected would be sufficient to overcome the pressure losses caused by the pipe system, simple fluid flow calculations were conducted. The head losses of the two inlet lines were compared and it was clear from inspection that the line with the valves and the filter would cause a larger pressure drop.

From the limited information supplied by Elmarco it was found the loss coefficient for a one layer filter (albeit thicker than the one the team selected) was equal to 1.64. Through concern for the possible blocking of the filter from ice particles (despite a low probability), a value of 10 was used instead for the filter. The loss coefficients of the entrance, valves and connector were calculated using the approximations from [19, table 8.2 page 289, figure 8.22 page 482] Using the Properties of the U.S. Standard Atmosphere [19, page 834] and the filter approximation, the pressure loss was calculated to be 0.17 Pa using [19, equation 8.36]. This is well below the pump performance in atmosphere, a pressure difference of 9 mbar from [15]. However, the pump might not operate at these standards, rigorous testing was carried out to make sure it does (section (13.3.4)).

8.5 Materials

Because of the nature of this experiment, a number of different metals were selected depending upon the applications. Although aluminium is preferred for many uses, it is not suitable for others.

8.5.1 Aluminium

The frame and structure of the experiment are constructed from prefabricated beam materials. Although aluminium is both light and easily worked, there are difficulties with such a balloon flight and stratospheric temperatures. Due to the high coefficient of thermal expansion, aluminium was deemed inappropriate for the piping due to leakage concern.

8.5.2 Steel

Steel is used for the piping. The low coefficient of expansion was the deciding factor for using the steel and since the amount of piping required is not large and the diameter small, the mass payoff was deemed acceptable.

8.6 Pump

The pump is a crucial component of Stratospheric Census. It is required to operate under the conditions prevalent in the stratosphere, being temperatures down to $-90°\text{C}$ and pressures of $1 - 2\,\text{kPa}$. Under these low pressure conditions - a medium vacuum - the lack of convective cooling also poses the risk of overheating. At the same time, power consumption should not exceed what can easily be provided with batteries and the pump should be light and small while still providing the necessary throughput of air.

Typical candidates are therefore vacuum pumps designed for the medium vacuum range (defined from $\approx 3\,kPa = 30\,mbar$ downwards). Usually, these

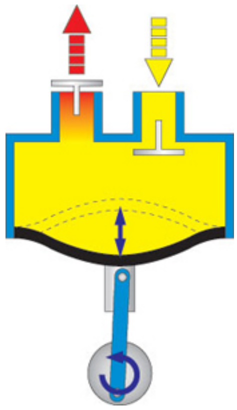


Figure 17: Diaphragm Pump

pumps are designed to produce a vacuum against atmospheric pressure. For Stratospheric Census, the pump works against the "ambient" medium vacuum which should have a positive effect on the possible throughput. On the other hand, the low temperature has a negative effect on the throughput as the molecules stick to surfaces much longer at low temperatures.

For a medium vacuum, the most used and reliable type of pumps are rotary-vane and diaphragm pumps.

The experiment uses a diaphragm pump (figure 17), for the following reasons:

- Diaphragm pumps are dry pumps, they do not outgas oil.
- The diaphragm itself insulates the air stream against contamination from the rest of the pump.
- Diaphragm pumps are reliable, readily available and economic.
- There is less friction than in rotary-vane pumps.
- A diaphragm pump has already been used successfully on a BEXUS balloon in the very similar SADFACE experiment [7].

Possible disadvantages of diaphragm pumps:

- Depending on the material of the diaphragm, it might become brittle in the cold and could therefore break.

Stratospheric Census uses the N 89 KNDC by KNF Neuberger [15].

8.7 Filter

8.7.1 Filter requirements

To get a meaningful detection with neutron activation analysis, the mass of the caught particles needs be at least 1 ppb (parts per billion) of the mass of the filter (see section (10.5)).

An estimate of the relative mass of the particles:

$$C = \alpha \frac{M_p}{M_f} = \alpha \frac{N m_p}{M_f} = \alpha \frac{n V m_p}{M_f} = \alpha \frac{n \phi t m_p}{m_f} \tag{2}$$

In equation (2), C is the relative mass of the caught particles, α is the sticking ratio, considering the amount of particles that are attached to the surface of the hose or that fly through, M_p is the total mass of the caught particles (kg), M_f is the mass of the filter (kg), N is the total number of particles, m_p is the average mass of the particles (kg), n is the particle density (m^{-3}), V is the total volume of air sucked in (m^3), ϕ is the air flux ($\frac{m^3}{s}$), and t is the total time (s) in which air is sucked in.

If one estimates values for the different quantities in equation (2) one can estimate the relative mass.

With $\alpha = 0.5$, $n = 10^5 m^{-3}$, $\phi = 2\frac{m^3}{\text{hour}}$, $t = 5\text{hours}$, $m_p = 1\mu g$ and $m_f = 100g$, one gets a relative concentration of:

$$C = 0.5 \cdot 10^5 m^{-3} \cdot 2 \frac{m^3}{\text{hour}} \cdot 5\text{hour} \cdot \frac{1\mu g}{100g} = 0.005$$

Of course, all of the values are very rough estimates. However, the estimated value is more than six orders of magnitude above the necessary value of $C = 1 \cdot 10^{-9} = 1\,\text{ppb}$, so even if all of the values are much worse than estimated here, it is still likely that the team can still detect particles.

The filter property that is relevant is really the flux divided by the mass. If the filter is twice as heavy, and the flux is twice as high, the detection is, in the end, the same.

This does not take into consideration the contamination.

8.8 Choice of filter

High requirements must be served by the filter in order to catch dust particles down to a size small as 0.3 μm. Also the filter must not be affected by the low temperature. Stratospheric Census uses the Nanospider ^{TM} Technology, developed by Liberec Technical University (Czech Republic) and manufactured by Elmarco. The filter along with the mounting is provided free of charge by Elmarco for Stratospheric Census. This type of filter consists of cellulose filtration material treated with PA6 polymer nanofibers 100 to 500 nm in diameter. During a test it was able to catch NaCl particles of 0.2 μm with an efficiency of almost 80 % where particles of 1 μm were captured fully. [20] The chosen filter with mass density of the nanolayer material of $0.19 g/m^2$ causes a pressure drop of $178 Pa$ which requires the pump to build up a pressure which is more than two times larger than ambient pressure.

A photograph of the figure mounting is shown in figure (18).

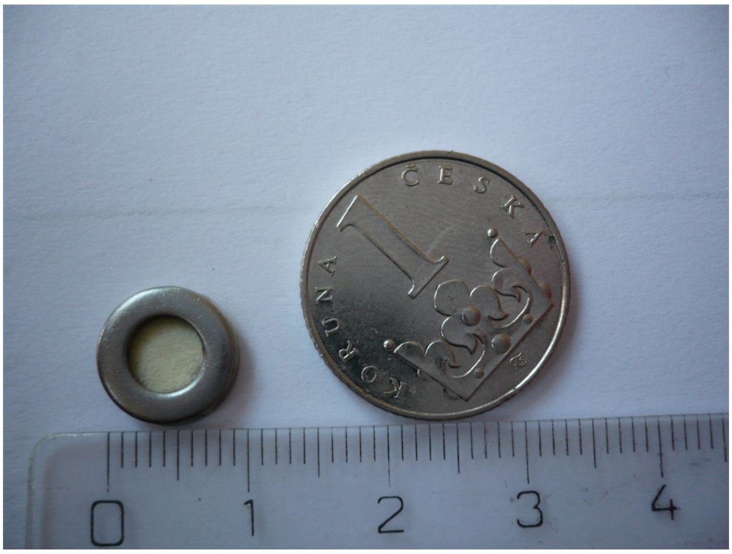


Figure 18: The ring shown on the left of the figure contains the filter. A czech crown and a ruler are shown for size comparison.

The analysis is done on both a filter that has flown and a control sample. Those are assumed te be identical before flight. The difference in the profiles obtained by Neutron Activation Analysis is then the collected material.

9 Software overview

9.1 Computer systems and data storage

Stratospheric Census is equipped with a microcontroller ATMEGA128-CAN, sponsored by chip45. It provides $4\,kB$ of non-volatile EEPROM and $4\,kB$ of volatile SRAM memory. Within the control box where electronics and microcontroller are housed, a temperature sensor monitors the thermal conditions. A heating element is provided to assure that the temperature stays within the operating range of the ATMEGA128, from $-55\,°C$ to $125\,°C$. It can be switched on as needed.

9.2 Qualitative software requirements

The experiment is launched with the filter valves closed and the pump operating at a low speed. During the ascent of the balloon, temperature and pressure are recorded and transmitted to the ground. Once the balloon reaches its floating altitude, the filter valves are opened and the pump cycled up with a command from the ground. However, if the uplink is not operational, this should happen automatically if pressure drops below a certain level or if a certain amount of time has passed since launch. Once the balloon leaves the floating altitude, this process has to happen in reverse order. (Close the filter valve, switch off the pump.)

The pump is controlled by the means of PWM (Pulse Width Modulation) to allow the setting of a specific voltage. At the beginning of operation, it can therefore be run at a lower speed. During the campaign, the number of cycles is then increased step-wise if pump temperature (risk of overheating!) permits.

The heating elements are controlled automatically by the microcontroller with reference to a threshold temperature. However, they can also be controlled manually from the ground if need arises. Data is stored in two different packet configurations, "data packet" (containing dynamic data, i.e. temperature, pressure and time) and "status packet" (containing data about pump, valve, heater status and operating mode). "Data packets" are sent every $10\,s$, "status packets" upon ground station request or when a status variable changes.

Based on these qualitative requirements, the operation of Stratospheric Census is structured into three different modes, defined in the following sections.

9.3 Normal mode

Ideally, the experiment is in 'Normal Mode' for the whole mission duration. Prerequisites for this are a working up- and downlink. The microcontroller then:

- monitors constantly pressure and temperature
- generates data packets from the current pressure and temperature at a standard interval of 10 s and transmits them to the ground
- expects an "OK" from the ground after every packet to assure that up- and downlink are working
- listens to commands from the ground station
- acknowledges commands from the ground station by sending an ``OK''-packet / status packet
- controls the heating elements automatically

9.4 Autonomous mode

'Autonomous Mode' is entered from 'Normal Mode' if more than 4 minutes have passed since the processing of the last command from the ground. (After 2 minutes without command, a warning is issued.) 'Autonomous Mode' is left if any command is received.

The microcontroller:

- monitors constantly pressure and temperature
- controls the pump and valves automatically
- listens for commands from the ground
- records data packets from the pressure and temperature sensors at a standard interval of 10 s and transmits them to the ground
- stores part of these packets in EEPROM memory
- determines whether the floating altitude has been reached by monitoring time and pressure
- controls the heating elements automatically
- controls pump cycles automatically to prevent pump overheating

- stores a status packet together with a data packet in EEPROM memory if a status change occurs

Whether the floating altitude has been reached is determined by comparing the current pressure and time with predefined values. If the time threshold has been passed or if the pressure has been below its threshold value for at least 2 min, another warning message is transmitted. After additional 2 min, the valves open and the pump starts unless some ground station interaction occurs before. The same procedure applies for the descent. As it is difficult to judge when descent will happen, pressure will be the only indicator for the stop of the experiment.

9.5 Further details

Technical details on packet structure, a complete flow diagram, etc. are given in section "Experiment software and autonomous functions", section (11.7).

10 Operation

10.1 Measured flight information

The following is measured directly using sensors:

- Four temperature sensors, one to measure the pump temperature, one to measure the control box temperature, and two at other locations in the experiment. This information is needed for heater and pump control.
- One pressure sensor to measure the ambient pressure. This is used to assess whether the experiment should be started.

10.2 Location and orientation in the gondola

The experiment needs to get air from outside the gondola. Contamination is lowest when viewing down. Hence, the experiment looks downward.

10.3 Pre-flight procedure

For contamination and interface reasons, several tasks were carried out shortly before the planned launch, from a few days up to half an hour. Throughout the launch campaign at Esrange, the team kept track of those tasks in TODO-lists and timelines.

10.4 Post-flight procedure

As requested by Esrange staff, instructions were written for the recovery crew that picks up the experiment after flight. The only required task was to pull the plug that says 'BATT'.

10.5 Post-flight analysis

After the retrieval of the payload, the filters are dismounted in a cleanroom at IRF and shipped to the Institute of Experimental and Applied Physics, Czech Technical University, Prague, Czech Republic. Subsequently, two techniques are used for analysis.

Electron microscopy will be used for evaluation of the main structure of the aerosols. The size gives useful information about the origin of a particle (volcanic, cosmic or contaminate). The spatial distribution of specific elements can be studied. An image of a filter similar to the one that will be flow can be seen in figure (18).

The core analysis technique is Coincidence Instrumental Neutron Activation Analysis (CINAA) [12], a technique able to detect the composition of multiple isotopes. This will be carried out by the Czech Nuclear Institute, using a neutron specific dose at Research Reactor LVR-15 for activating sample for about 100ppm strong analysis by gamma spectroscophy on site focusing on heavy metals. We are expecting to find transitions between specific types of isotopes of Fe, In and Co mainly. These isotopes were not there previosuly as the previous calibration analysis confirmed (personal corespondence, results come-up soon) The method is very precise and can be used to detect a sub-ppm fraction of elementary abundance for up to 74 elements [16] [5]. This technique will be used both on the filter that has been flown, and on the filter that has not been flown, so that the structure of the filter itself can be removed by digital post-processing (simple subtraction).

Heavier elements have larger nuclei, therefore they have a larger neutron capture cross-section and are more likely to be activated by fast neutrons. That is of great benefit, because the team is mostly interested in those heavy elements, although only present in stratosphere in trace amounts. The method is nearly free of any interference effects as the samples are transparent to both the probe (n) and analytical signal (gamma ray). CINAA is applied instrumentally (no need for sample digestion or dissolution), so there is little if any opportunity for reagent or laboratory contamination. The team will focus on iron, nickel and cobalt isotopes, and will try to find out very spare ones of iridium and similar as well. The team expects isotopes of those elements (Fe, Co, Ni) originating from volcanic eruptions in slightly altered than naturally occurring well-measured ratios. Heavier nuclides are present as well [18]. A main advantage of the CINAA is the possibility to distinguish terrestrially uncommon isotopes, thus recognising them as of cosmic origin. Among others, Fe(60) or Ni(60) can be some of the clearest indication of an extraterrestrial source. Also the Fe(57)/Fe(54) relative composition differs strongly for terrestrial and cosmic sources.

11 Experiment interfaces and design requirements

11.1 General design requirements

11.1.1 Fault tolerance design

11.1.1.1 Electronics A risk of failure of the electronics subsystem must be kept as low as possible since a complete failure of the electronics would result in a failure of the experiment. However a complete failure is unlikely due to excessive testing. In the worst case the microcontroller fails. This is discussed in section (11.1.1.2).

In addition single components of the electronics can fail.

1. The power supply connection can fail. This risk is kept low by having redundancy strings of batteries connected via a diode to the other battery packs.

2. If the pressure sensor fails the system can still be controlled by the ground station. A double failure of the sensor and a connection loss might result in a complete failure of the experiment when it happens during critical phases, i.e. opening and closing the valves.

3. Failures in valves or pump might result in false conclusions drawn from the neutron activation analysis.

11.1.1.2 Microcontroller safety and risk of failure No immediate safety risk stems from the microcontroller itself.

As the hear of the experiment in terms of controlling pump, heaters and valves, a microcontroller malfunction poses a high risk for total failure of Stratospheric Census.

- Loss of microcontroller power: Problems with the microcontroller power supply can occur. Temporary power loss leaves the chance of recovery (microcontroller reset), total power loss is fatal.

- Microcontroller in infinite program loop: This is prevented by using the watchdog functionality, very low risk.

- Wrong command interpretation: Commands are secured with a checksum, very low risk.

- Temperature outside microcontroller operating range: If temporary, very low risk for the experiment. If permanent, possible loss of the experiment.

- Loss of a sensor or communication with a sensor: Loss of the temperature sensor in the control box can be fatal for the microcontroller. Loss of the temperature sensor on the pump can be fatal for the pump. Loss of pressure sensor in conjunction with loss of ground communication (Autonomous mode) can lead to a delayed experiment start.

11.1.1.3 Structure In order to avoid failure propagation for the structural components, most components are bracketed to a frame structure that connects to the strong and rigid exterior frame. In the case that a component does manage to break away from another, they should remain fixed to the other components. Of concern are the large mass components such as the pump and actuators. Particular care has been taken to ensure that they are secured and redundant beams have been used.

Although the pump used is small and not running at a high frequency, failure propagation is still a concern. Although the experiment should withstand catastrophic failure of the pump, it is of concern for other experiments.

11.1.1.4 Single point failures Due to the limited scope of this project, multiple redundancies were not possible for many of the components, The high cost of the pump and actuators means that only one pipe system could be used. Unfortunately, this results in multiple single point failure possibilities.

In order to lower the possibilities of pump failure during flight, the pump that has been chosen has been previously used in the stratosphere and seen to start and run in temperatures much below the specifications. However, if the bearings seize or another malfunction occurs, flow will be limited or cease entirely.

The valve and actuator assemblies are both single points of failure but design decisions have been made to reduce this impact. Critical failure will occur if the valves fail to open at the beginning of sampling. However, if failure occurs during sampling, the valves should automatically switch back and protect the material collected from contamination. If the valves freeze shut or open, as the temperature rises again, control will either be regained or they will automatically close. In this way, although critical failure can occur if the valves can not be opened, failure during sampling should not be fatal to the results of the experiment.

11.1.2 Safety concept

The experiment does not contain any electro-explosive devices, pressurised containers or radioactive sources. It contains batteries. Batteries can be chemically hazardous when leaking, but this should not happen.

The experiment contains a pump that causes vibrations and can thus cause problems for other experiments on or near the gondola.

All mechanical parts comply with Swedish industry safety standards. All moving parts are either completely or practically sealed off, no specific instructions regarding safety are needed for this.

11.2 Mechanical interfaces

11.2.1 Accommodation requirements

This total frame requires 350*300*200 mm.

The 300*200 mm face must face downwards and have access to the atmosphere in order to take samples whilst minimising contamination. The design is flexible in case arrangement changes are made close to the launch.

11.3 Thermal interfaces

11.3.1 Thermal design

11.3.1.1 Thermal design requirements For different subsystems different thermal requirements apply. Critical part of the control box is the pressure sensor, which provides compensated data from $0°C$ to $85°C$. The battery box should be kept on a level as high as possible to $70°C$ (Figure (19)) to get maximum performance. The pump specifications state that it will operate between $5°C$ and $40°C$. However, it has flown in the stratosphere before and operated without any active thermal control, as long as it starts running at high temperatures. Due to the temperature fluctuations, critical elements of the structure must take into account the changes in size.

11.3.1.2 Thermal design description A 5W heater is used to actively control the temperature of the control box. It was verified by testing that this works as it should. The design is finetuned with thermal paste.

The temperature of the battery box is controlled passively by thermal insulation. Battery self-heating is used to keep the desired temperature.

In order to reduce the chances of the heater getting too cold or seizing when operation begins, it is started before launch. This was tested beforehand.

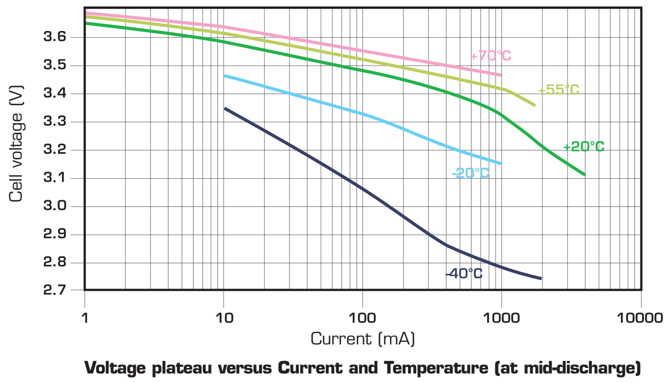


Figure 19: LSH 20 performance

In order to avoid loss of seal due to changes in pipe diameters as the temperature varies, the pipes are made of steel. Flexible sealant ensures air-tightness.

11.3.2 Thermal interfaces

The experiment has conducting interfaces through the structure to the gondola. Convection can be neglected in the stratosphere.

11.3.3 Temperature monitoring

The temperature is continuously measured at four points on the experiment: on the PCB board, on the microcontroller, inside the battery box and on the pump surface.

11.4 Power interface requirements

11.4.1 General interface description

For the control circuit a potential of 5 V is needed which is taken from the power bus (at $3 \times 3.6\,\mathrm{V} = 10.8\,\mathrm{V}$). The 5V control circuit supply is regulated while the power bus is not. This is not necessary since no sensitive components are connected to latter.

11.4.2 Experiment power requirements

An overview of the power requirements can be seen in table (2). This table yields a total charge consumption of 15.45 Ah. For redundancy reasons, two

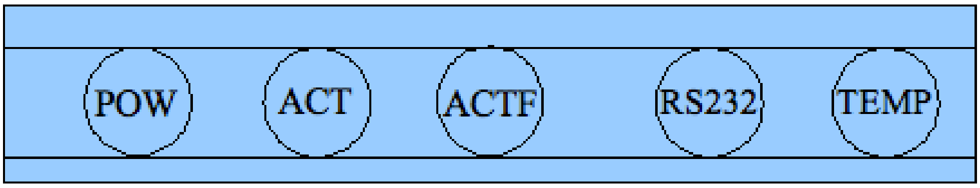


Figure 20: Connector diagram. See text for an explanation.

strings for each battery pack are used. Each of them has 3 batteries. Thus a total of 12 batteries are used.

Component	**Power [W]**	**Potential [V]**	**Current [mA]**	**Duration [h]**	**Charge req [Ah]**
Control system	2*	5	0.4	10	4
Regulator	3*	10	0.4	10	3
Heater	5	10	0.5	5	2.5*
Actuator	18	10	1.8	0.25	0.45
Pump	11	10	1.1	5	5.5

Table 2: Experiment power requirements. The figures marked with an asterisk (*) are based on estimation.

11.4.3 Interface circuits

The main PCB is connected to the E-link provided by Esrange via a twisted three wired cable. On the E-link site it is connected via a MIL-C-26482 series I connector. The control box provides a circular socket for this interface (see section (11.5)). The MIL-STD connector was borrowed from Esrange for the time of flight.

11.5 Connector and harness requirements

11.5.1 Interconnection harness block diagram

Figure (20) shows the external interfaces provided by the control box. The circles indicate the individual sockets and are denoted with acronyms having the following meaning:

POW Power line in

ACT Actuator and pump interface

RS232 Serial connection

TEMP Interface to three external temperature sensors (two optional)

11.5.2 Interconnection harness characteristics

All interconnections are foil shielded with the shield grounded to the control box.

11.5.3 Connector types

For all connectors the 680 series manufactured by Binder is used [2]. All sockets are female to protect the circuit from accidental outside shortening. Thus all connectors, including the power connector are male. The latter does not cause any danger due to voltages of maximum 12V.

As mentioned before, the MIL-STD connector are borrowed from Esrange for the time of ight.

11.5.4 Connector pin allocation

See appendix (A.3) for a full table with pin allocations and configurations.

11.6 On-board data handling interface requirements

11.6.1 E-Link connection

An RS-232 connection to the E-Link unit is required. It is be used at 9600 bps, with one packet comprising 1 start, 8 data, 1 stop bit. There is no flow control.

11.6.2 Channel allocation

Table (3) below shows the interface channels used.

Interface	Main
Telemetry & Monitor Downlink	1
Telecommand Uplink	1

Table 3: Experiment OBDH interface channels

In the E-Link connection, these channels are shared with other experimenters.

11.6.3 Bit rate requirements

Stratospheric Census does not continuously transmit data. Data packets are sent every 10 s, status packets upon request and/or status change. The operational scenarios, as outlined in the software descriptions are 'Normal Mode' and 'Autonomous Mode'. For these, the bit rate requirements are:

- Worst-case Minimum ('Autonomous Mode'): 0 bit/s
- Normal ('Normal Mode'): In a 10 s interval, it has to be possible to transfer one data packet and, if need arises, one status packet (downlink). A safe lower limit therefore are 50 bit/s.

If, in 'Normal Mode', this bit rate cannot be sustained, the buffer of the E-Link unit would slowly be filled up by the Stratospheric Census microcontroller.

11.6.4 Timing

No requirement on timing information for the experiment on the balloon. A real time counter, counting the seconds since power-on, will provide a timestamp for the packets. On the ground, this can be matched to real clock time.

11.6.5 Monitoring

Stratospheric Census monitors the temperature on the pump and in the control box housing the electronics. For experimental purposes, the pressure is measured as well. Based on the temperature values, either the microcontroller (in 'Autonomous Mode') or the ground station (in 'Normal Mode') takes the necessary actions. Commands are verified by the microcontroller based on a CRC-checksum, their execution acknowledged either by an OK-packet and/or a status packet.

11.6.6 Electrical interface circuits

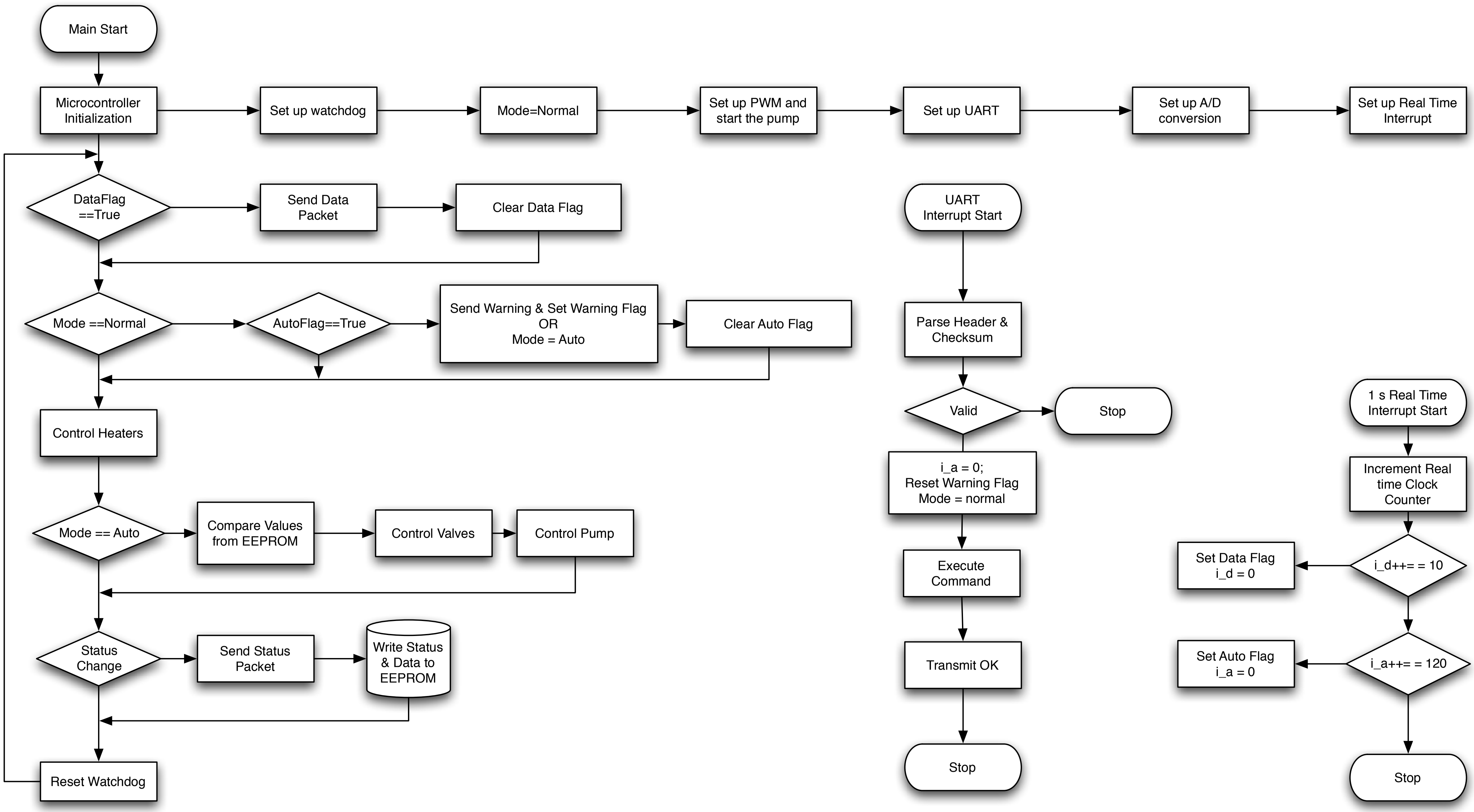
Except for the RS-232 connection, there are no electrical interfaces outside the experiment. Since RS-232 uses a GND-line, the whole experiment has to be grounded to the gondola to share a common ground with the E-Link unit.

11.7 Experiment software and autonomous functions

11.7.1 Software flow diagram and functional requirements

The software flow diagram for the microcontroller (next page) shows the complete code structure, including the switching of modes and the interrupt handling. Transmission to the ground and data saving to the EEPROM are indicated as well.

Stratospheric Census: Microcontroller Flow Diagram



11.7.2 Design for redundancy & shutdown

The 'Autonomous Mode' is designed to provide absolute independence from the ground station in terms of controlling the experiment. Since no loss of connection was encountered during flight, it was never used. Together with the fact that all data taken during "Autonomous mode" is stored in memory, this makes the mission immune to temporary up- and downlink failures. For longer ($\gg$ 30 min) up- and downlink failures, not all data can be stored due to finite memory capacity. Only datasets from the last 30 min will be available.

In the case of a temporary power shutdown, the microcontroller will recover on its own, albeit the data stored in SRAM will be lost. The microcontroller watchdog will guarantee a reset in case of an accidental infinite loop in the code.

11.7.3 Pump operating modes (see Flight Report for actual operation data)

The pump can be operated at different speeds, depending on the supply voltage. This supply voltage is controlled by the means of PWM and a MOSFET. In order to avoid a pump start in the stratosphere, the pump will be in a low-cycle operating mode during ascent and - upon reaching the desired altitude - will cycled up to full speed. Once the experiment will be started (valves open) the pump voltage will be increased to 12 V, monitoring the temperature. Should the maximum temperature be reached, the voltage is lowered again until a stable and thermally acceptable working point has been found. The details of the control loop have were determined in a thermal test.

11.7.4 Packet definitions

"Data packets" and "status packets" have a length of 21 bytes, including a CRC checksum byte to assure data integrity and a timestamp (from the real time counter). A data packet and a status packet are saved in the EEPROM after a status change. (A status change can be switching the heater on/off, changing the pump cycle, etc.) In "Autonomous mode", data packets are also saved periodically. Assuming a data taking rate of once every 10 s, the 4 kB EEPROM on the ATMEGA128 could save data for $\approx$ 30 min. This interval will be chosen. The data packet looks as follows:

Byte	1	2	3	4-5	6-7	8	9-10	11-12	...
Content	$	P	D	ID	time	,	temp board	temp μC	...

...	13-14	15-16	17-18	19-20	21
...	temp pump	temp batt	pressure	CRC checksum	\r

The first byte ($) indicates the start of the packet, the second byte identifies the sender ("P" = probe), the third byte describes the content ("D" = data). A two type ID assures the correct identification of every packet.

The status packet is similar ("S" = status):

Byte	1	2	3	4-5	6-7	8	9-10	11	...
Content	$	P	S	ID	time	,	pump	heater	...

...	12	13	14	15-16	17
...	valve A	valve B	mode	CRC checksum	\r

"Command packets" are kept shorter to reduce the risk of corruption during transmission.

Byte	1	2	3-8	9	10
Content	$	G	command	CRC checksum	\r

The first byte ($) indicates the start of the packet, the second byte identifies the sender ("G" = ground), bytes 3-9 are for the command itself and the checksum. For a specific command, the CRC checksum is predefined (since there are no variable bytes in the packet) and can be hardcoded into the code (i.e. it does not need to be calculated).

11.7.5 Telecommand definitions

The possible commands are:

- `''OK''` , to signal a working connection every 10 s
- `''ELLO''` , to check the uplink (handshake)
- `''VO'' + ID`, to open the valve with ID (A or B)
- `''VC'' + ID`, to close the valve with ID (A or B)
- `''HEON'' + ID`, to switch on the heater with ID
- `''HEOF'' + ID`, to switch off the heater with ID
- `''PUMP''` + 2 bytes,
  to switch the pump to a certain operating voltage (0=off, 255=full speed)

- ``GETS'' , to get the current status packet
- ``STTE'' + 2 bytes,
  to set the threshold temperature for start and stop of the census phase (for automatic mode), is written to EEPROM, preset to a value TBD before launch
- ``STTI'' + 2 bytes,
  to set the number of seconds from launch onwards until the start of the census phase (for automatic mode), is written to EEPROM, preset to a value TBD before launch
- ``AUTO'' to switch the microcontroller manually to "Autonomous mode"
- ``GETP'' + 2 bytes ID, to get the packet (data or status) with ID that was previously saved in memory
- ``GETD'' to get a current data packet

The possible responses from the balloon are:

- a "data packet", responding to the command ``GETP'' ``GETD''
- a "status packet", responding to the command ``GETS''
- command + "OK", responding in all other cases

11.7.6 Handshaking

Data packets serve as a heart beat signal from the experiment as they are transmitted every 10 s and signal a healthy downlink. The ground station responds with ``OK''. Since it is not possible to determine from the experiment whether the uplink is working, the ground station can send a ``ELLO'' - command, waiting for a ``ELLOOK'' .

11.7.7 EEPROM

The EEPROM can accommodate 4 kbyte of data. 1 kbyte is reserved for status change packets and their corresponding data packets, the remaining 3 kbyte are for the saving of data packets during autonomous mode (can be sustained for 30 *min* until old data has to be deleted).

11.8 Electromagnetic compatibility requirements

11.8.1 General EMC requirements

Radiated emission is kept as low as possible using filters for outgoing connections. Shielded wires for pump and external sensors after verification are not necessary. The main part of the electronics is placed in a metal control box. The design is sufficient also to reject interference from outside the experiment.

11.8.2 Specific EMC requirements

The external temperature sensors form a high impedance line, susceptible to picking up noise. Apart from the above stated electronical action taken, the software will compare several measurements to filter out incorrect measurements.

11.8.3 Grounding

In addition to grounding the experiment in itself it is grounded to the gondola. This is inevitable, since a connection between the control box and the E-link has to be established. A grounding diagram can be found in figure (23) in appendix (A.2).

11.9 Cleanliness design and contamination control requirements

Particles in the stratosphere can be of volcanic, extraterrestrial or anthropogenic origin. A particular case of particles from anthropogenic origin are particles that originate from the balloon, the gondola, or its payload (including the own experiment) and caught by the filter immediately. Those are particles that the team is not interested in and are outside the scope of our experiment; they are thus considered to be contamination. There may also be ice particles that are neither anthropogenic, nor aerosols, though those are rare in the very dry stratosphere.

Apart from the common composition of materials from which the experiment structure is built, there exists a local deviation from the standard Earth isotope ratio conditions. The balloon launch platform contains material from the regional iron-ore mining, thus introducing a magnetite contamination. Fine grains may stick to the aluminium gondola and detach later during the flight, possibly entering the experiment. The iron ore from Kiruna has slightly specific ratio's of nuclide compositions.

It is safe to assume that all surfaces and materials in the balloon-gondola-system will outgas. Outgassing can result from desorption, diffusion and decomposition. [23] The amount of mass loss due to diffusion is given by:

$$\frac{dm}{dt} = q_0 \frac{e^{-\frac{E_a}{RT}}}{\sqrt{t}} \tag{3}$$

In equation (3), q_0 is a reaction constant, E_a is the activation energy, typically between 5 and 15 $\frac{\text{kcal}}{\text{mole}}$, R is the universal gas constant, T is the temperature and t is the time. This equation was derived for a vacuum. The stratosphere is no vacuum, but the atmospheric density is considerably lower than in the lower troposphere, so this may be a reasonable approximation.

If one assumes that particles travel straight paths relative to the balloon after outgassing, one can estimate the amount of impacted particles using view factors. Unfortunately, this assumption cannot be made, because the pump is actively sucking air from the environment. The situation will thus be considerably worse.

It is difficult to estimate theoretically not only how many particles will diffuse from the surfaces, but also how many of those will be caught in the air flow through the filter. It depends on many variables, many of them poorly known: the viewing direction for the hose, the distance to surfaces outgassing particles, the path that those particles travel (whether they fall down or float), the sucking power of the pump (from what distance such particles will be caught), the presence of other experiments outgassing particles, and probably a number of other factors. The "worst case scenario" approach does not work either; the worst case would be catching an outgassed particle big enough to block the valve completely; this is probably a highly unlikely scenario.

A good knowledge of the profiles of stratospheric dust is required to be able to tell apart contamination from actual measurements in the neutron activation analysis.

Despite all this, a very rough estimate is made.

The following sources of contamination are identified:

- The balloon
- The gondola
- Other experiments
- The own experiment

For each of those, the amount of contamination for the experiment can be approximated as the product of the outgassed mass times the fraction of outgassed mass that impacts the surface.

Source	amount (g/hour)	fraction	impact (g/hour)
Balloon	10^2	10^{-5}	10^{-3}
Gondola	10^{-1}	10^{-4}	10^{-5}
Others	10^{-2}	10^{-5}	10^{-7}
Us	10^{-3}	1	10^{-3}
Total	10^2	$2 \cdot 10^{-5}$	$2 \cdot 10^{-3}$

Table 4: Estimates for outgassing amounts. Note that those are extremely rough estimates and that the estimated values can be off by three orders of magnitude or even more.

In table (4) are estimates for the outgassed mass. The figures in this table are highly unreliable. The team estimates to receive around 0.1 gram of stratospheric dust and 2 milligramme contamination per hour. This would be an acceptable contamination level, as it would in total be around 1% of the mass of the captured aerosols, which would in turn be around 0.1% of the mass of the filter (all very rough estimates).

11.9.1 Mitigation

Even without knowing how much contamination the team can expect, it can list a number of techniques to use to prevent contamination as much as possible.

Contamination from the balloon is expected to be worst during launch and during descent. Our experiment has a front valve preventing any particles from entering the hose during launch and ascent up to stratospheric altitude. This valve is as close to the front as possible, so that as few particles as possible can stick to a surface between the valve and the ambient atmosphere. This valve will close again before descent, so that contamination during descent and impact is as low as possible.

The distance between the pump (with the filter in front) and the ambient air is as small as possible, so that the surface area of the pipe, which will outgas particles, is minimised.

The preferred viewing direction for the experiment is straight down. This minimises contamination from the balloon.

11.9.1.1 Cleaning the experiment In order to minimise contamination, it is required that the pipe subsystem is cleaned before flight. The system was cleaned by pulling a brass rod with a polyester cleaning cloth with naphta through the pipe.

12 Ground station

12.1 Ground control and electrical ground support equipment

The equipment that is used as EGSE (Electrical Ground Support Equipment) for instrument level and system level check-out testing is also used for experiment ground control during flight and will be referred to as "ground station" below.

12.1.1 Concept

The ground station is kept as simple as possible using standard hardware (a computer workstation and a notebook as a spare) and both standard and custom-made software. The interface between the experiment on the balloon and the ground station is realised through the E-Link connection. A simulation of the Esrange E-Link was part of the EGSE.

12.1.2 Hardware description

A standard PC with ideally two serial ports (for redundancy reasons) and a replacement unit (notebook), both running Windows XP. A USB-serial converter as a backup. No electrical stimulators were used during check-out.

12.1.3 Network interface

A RS-232 connection to the E-Link ground unit, operated at 9600 bps, hardware flow control, 1 start, 8 data, 1 stop bit.

12.1.4 Software description and user interface

Stratospheric Census can be controlled from the ground either by a simple terminal program or by the Stratospheric Census Groundstation software. This software is written in the JAVA language and visualizes the incoming data and status packets. Additionally, this data is saved in a log-file using the HTERM terminal software. Commands are easily executed via simple command buttons ("Experiment Commands"), the response (status packet and/or OK) is displayed. The current status of the connection to the experiment is shown ("Up-/Downlink"). If a mission critical command is issued, the operator will be asked to confirm the command in a dialog box.

A screenshot of the ground station can be seen in figure (21).

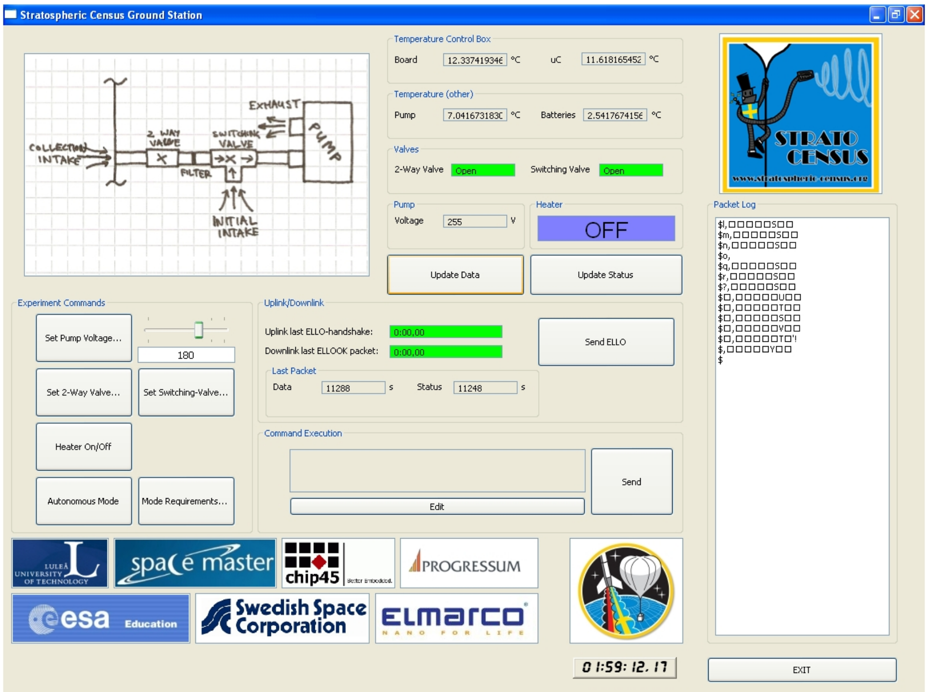


Figure 21: Ground station user interface, during flight

12.1.5 Compliance

No further action is necessary for the electrical equipment as these are standard components. In general, the working conditions for the ground station are uncritical and the same during development and flight, only satisfactory operation during all other test runs is necessary for compliance.

12.2 Ground operation requirements

If the experiment is in 'Autonomous Mode', no interaction from the ground is necessary.

If the experiment is in 'Normal Mode', the ground operator is mainly responsible for the control of the pump and the valves and the supervision of all flight data.

13 Verification and testing

13.1 Verification

Verification of the experiment is an important part of the project. All designs are made such that verification and testing is possible, and a significant amount of time is reserved for this in the time plan.

The objective of the verification is to make sure that all subsystems, as well as the whole system, comply with the specifications, requirements as well as the boundary conditions as defined by Eurolaunch.

Testing is a very important part of verification, particularly when the experiment to be verified will be out of human reach when it is run, such as is the case with an experiment flying on a stratospheric balloon.

13.2 Testing

The experiment test matrix, presented in table (5), summarises what kind of tests have been carried out.

Tests can be divided into tests that verify that the own experiment is working, and tests that verify that the experiment is meeting the requirements for flight (e.g., not harming others and not harming the flight train). First the subsystems were tested individually and then the whole subsystem was tested several times.

13.3 Subsystem tests

13.3.1 Microcontroller

Microcontroller qualification testing can be structured into the following parts:

1. Test of operating modes and operating mode switching - PASSED
2. Test of sensors - PASSED, pressure sensor not functional!
3. Test of memory management - PASSED
4. Test of heater control - PASSED
5. Test of pump temperature control - PASSED
6. Test of valve control - PASSED

Experiment unit	Mechanical Interface Inspection	Mass properties (tbl. 9)	Electrical Performance Test (tbl. 6)	Functional Test	Strength Test	Sine Vibration	Random Vibration	Shock Test	Low Pressure	EMC	Calibration	Thermal Properties
Control box (sec. 13.3.2.1)	M	M	M	F								
Battery box (sec. 13.3.2.2)	M	M	M									
Pump (sec. 13.3.3)	M	M		F					A			
Filter	M											
Microcontroller (sec. 13.3.1)				F								
Sensors	M	M		F							C	
Frame (sec. 13.3.4)		M			A			A				
Total (sec. 13.4)	M	M		F					A	A		

Table 5: Experiment test matrix. 'M' means that a quantitative measurement has been done. 'A' means that it has been qualitatively determined whether the (sub)system meets the requirements (e.g. it doesn't break, doesn't harm). 'C' means calibration has been performed by testing. 'F' is a functional test, to see if everything works as it should. Details on all tests can be found in the text, in particular in the indicated sections and tables.

7. Test of 'Autonomous Mode' experiment control - PASSED, last minute changes at ESRANGE necessary!

8. Test of commands and communication link - PASSED

9. Test of command parsing, command rejection and CRC checksum processing - PASSED

Most of these were simple works / does not work tests. However, for heater control, pump control and the 'Autonomous Mode' experiment control in general, the test of the microcontroller code had to happen in conjunction with temperature simulations. This way, the reaction of the control loops can be checked.

13.3.1.1 Microcontroller qualification requirements The microcontroller is qualified for flight if it:

1. has full functionality - final test PASSED October 1st.

2. successfully passes a long-term running test (at least 5 h) in 'Normal Mode' - PASSED.

3. successfully passes a long-term running test (at least 2 h) in 'Autonomous Mode' - PASSED after changes.

4. successfully controls the experiment while it is in the space simulator - the space simulator was not used.

5. successfully controls the heater under varying (fluctuating) temperature - PASSED in the thermal chamber. conditions.

The test of 'Autonomous Mode' was part of a full worst-case test including

- simulated loss of communication, several times during ascent and during floating - PASSED

- fast temperature fluctuations (simulated by stimuli or real) in the $-50\,^\circ$ to $50\,^\circ$ range - PASSED, not fully simulated.

- loss of power during ascent, floating and in 'Autonomous Mode' - PASSED

Several iterations of testing-updating-testing were performed, until the microcontroller met the requirements.

13.3.2 Electronics

13.3.2.1 Control box All electronic components are commercial with different industrial standards. All critical components are inside the heated control chamber, which should always be kept between 0 °C and 85 °C to make use of the internal calibration of the pressure sensor in this range.

The electronic box has been tested thermally using a thermal chamber. The temperature was raised from room temperature up to 50 °C. The temperature sensors were calibrated using this thermal chamber. No flaws were detected during this.

The electronic box was placed in the vacuum chamber, without any connection to outside. The pressure in the vacuum chamber was rapidly reduced to 40 kPa.

No bursts of components were detected and all soldering spots remained faultless.

13.3.2.2 Batteries The batteries will according to their manufacturer lose or gain performance depending on there temperature (see figure (19))

The thermal battery test was performed by placing one battery in the thermal box. This battery was fixed with insulation foam. A current of 1 A was drawn out of the battery. During this, no extraordinary increase in temperature was measured.

From this, it can be concluded that no thermal paste between the batteries and the box will be necessary. However, the system will behave differently in vacuum, and for that reason, a temperature sensor is placed on the batteries.

13.3.2.3 Electrical functional performance In table (6), the electrical function performance as measured during testing is summarised.

13.3.3 Pump: Thermal test

The pump is ready for flight if it is in working condition and can be kept from overheating under stratospheric pressure and temperature conditions.

The pump was tested under vacuum conditions and under thermal conditions. The pump did not break when tested in vacuum conditions. In the thermal test, the temperature of the pump was gradually reduced and it was tested whether the pump was still running and whether it was possible to switch it on or off. Down to −46 °C degrees, it was possible to turn it off and on again and the pump stayed on if it was already running. However, between −30 °C and −46 °C degrees, it occasionally failed when trying to

	Grid		Battery	
	U [V]	I [A]	U [V]	I [A]
all off	10.3	0.43	10.4	0.44
ACT A open	10.3	0.21	10.5	0.221
end position	10.3	0.14		
ACT A close	10.3	0.11		
ACT B open	10.3	0.20	10.5	0.20
end position	10.3	0.14		
ACT B close	10.3	0.99	10.6	0.102
heater on	10.3	0.49	10.4	0.49
pump on	10.3	0.30	10.4	0.30
total		1.11		

Table 6: Electrical functional performance test. The voltages and currents were measured with a power supply from the ordinary electrical grid, and with the batteries for the experiment. For most of the components, the values are fairly close to each other.

turn it on. Cycling (rapid on and off) had to be performed. This experience was used during flight.

13.3.4 Structure

Several tests were applied to the frame to make sure it is adequate for the full operating range.

1. A static load of 86 kg was applied to the frame.
2. A shake test was performed by shaking the experiment by hand.
3. The frame was dropped from a level of one meter.

The conclusion of the tests was that the frame is adequate.

13.4 Full functional test results

At several iterations, an overall function test was carried out. Initially, this was done while still running from the power grid, later it was tested from batteries and finally at Esrange. During those iterations, some flaws in the ground station software were detected and corrected.

13.5 Limited life time elements

Batteries have a limited lifetime and also a continuous performance degradation during flight. This degradation mainly depends on temperature and the design was verified during the testing phase.

Part IV
Project management

14 Project management

14.1 Organisation and responsibilities

The team of Stratospheric Census consists of five ambitious students, four from Europe and one from Australia, all studying in the ERASMUS Mundus Master Program “Space Science & Technology” (“Spacemaster”). The team members had prior experience in the design of balloon payloads through a CANSAT (“satellite” in a drinking can) competition in the first semester of the study programme. We are:

- Mark Fittock from Australia
  As a Mechanical Engineer, his responsibilities were:
  - Requirements Evaluation
  - Fluid Flow Analysis
  - Mechanical Design
  - CAD Modelling
  - Stress Analysis
  - Mechanical Construction
  - Mechanical Testing
- Gerrit Holl from the Netherlands
  - Scientific background: particularly the atmospheric science background, researching expected results, aerosol concentrations and composition, origins, etc.
  - Contamination requirements and estimates of amount of contamination
  - Report coordination; collecting inputs from various team members and combining this into a single LaTeXdocument (together with Martin Siegl)
  - Keeping track of the component list and the finances (together with Martin Siegl)

  - Working on the website and the blog (together with Martin Siegl)
  - Acquirement of the stickers, both with the team logo and with the sponsor logos
  - Note taking during the meetings.
  - Small assistance tasks throughout the project

- Martin Rudolph from Germany
  Martin's field of work was the electronic circuit design and the power budget.

  - Design, implementation and verification of the electronic and power subsystem
  - PCB design and soldering
  - Handling of electronic component orders
  - Electronics risk analysis
  - Electronics electromechanical and sensor interface design
  - Thermal design of control and power subunit
  - Contact with ESA (with Martin Siegl)

- Martin Siegl from Austria
  Martin was the groups' Software Engineer and took over various administrative tasks.

  - Design and implementation of the ground station software
  - Design and implementation of the on-board microcontroller software
  - Software integration and functional testing
  - Thermal testing (with Martin Rudolph)
  - Proposal presentation at ESA ESTEC
  - Sponsor acquisitions: PROGRESSUM, chip45
  - Order handling of mechanical components
  - Contact with ESA (with Martin Rudolph)
  - Homepage design (with Gerrit Holl) and public outreach (press contacts)

- Jaroslav Urbář from the Czech Republic

  - Original idea of Stratospheric Census and team formation

- Initial feasibility studies for using specific system components. Arranging sponsorship by Elmarco, providing sample test filters and final mounted filters free of charge.
- Preliminary filter testing and filter structure imaging analysis using electron microscope, MBU CAS, arranged by Ilona Urbarova, free of charge.
- Organisation and agreement with IEAP CTU and INP REZ to analyze the gathered samples, using multiple advanced physical and nuclear methods, mainly INAA, free of charge.
- Estimations of detectable nuclide levels in the sample, using various analysis methods with pending final composition results compiled after measurements done.

As a team comprised of five different nationalities, from ESA member countries, an ESA associated country and a non-ESA country, the team is proud to reflect the European spirit of ESA in a global cooperation within our group.

14.2 Relation with various organisations

IRV The project has been registered as a course with the Department of Space Science (Institutionen fr Rymdvetenskap, IRV), part of Luleå University of Technology (LTU), based in Kiruna, Sweden. The course supervisors were Kjell Lundin and Alf Wikström. IRV is also one of the funding organisations, providing 5000 SEK for parts (primarily electronic components) to be ordered via the institute.

SSC/Esrange The balloon was launched from Esrange, the launch facility in Kiruna, Sweden operated by the Swedish Space Corporation (SSC) at the 8th of October, 2008. Between April 20 and April 26, a training week was organised at Esrange during which all groups, including the Stratospheric Census group, in both the BEXUS and the REXUS campaigns, presented their PDR's and discussed those with a panel of experts from ESA, DLR, SSC and SNSB.

Eurolaunch Eurolaunch is a cooperation between DLR and SSC. Eurolaunch organises and pays the launch of the BEXUS 7 balloon.

ESA/ESTEC The European Space Agency (ESA) is heading the BEXUS campaign and sponsoring the project by funding transportation and living costs for the team members at ESTEC and Esrange.

IRF The group is close to the Swedish Institute of Space Physics (IRF) and has usei some resources available at the IRF for testing the experiment.

CTU IAEP At the Czech Technical University Institute of Applied and Experimental Physics (CTU IAEP), the final analysis is carried out. The IAEP pays for the analysis, which costs more than 500 euro.

Part V

Appendices

A Electronics

A.1 Circuit diagram

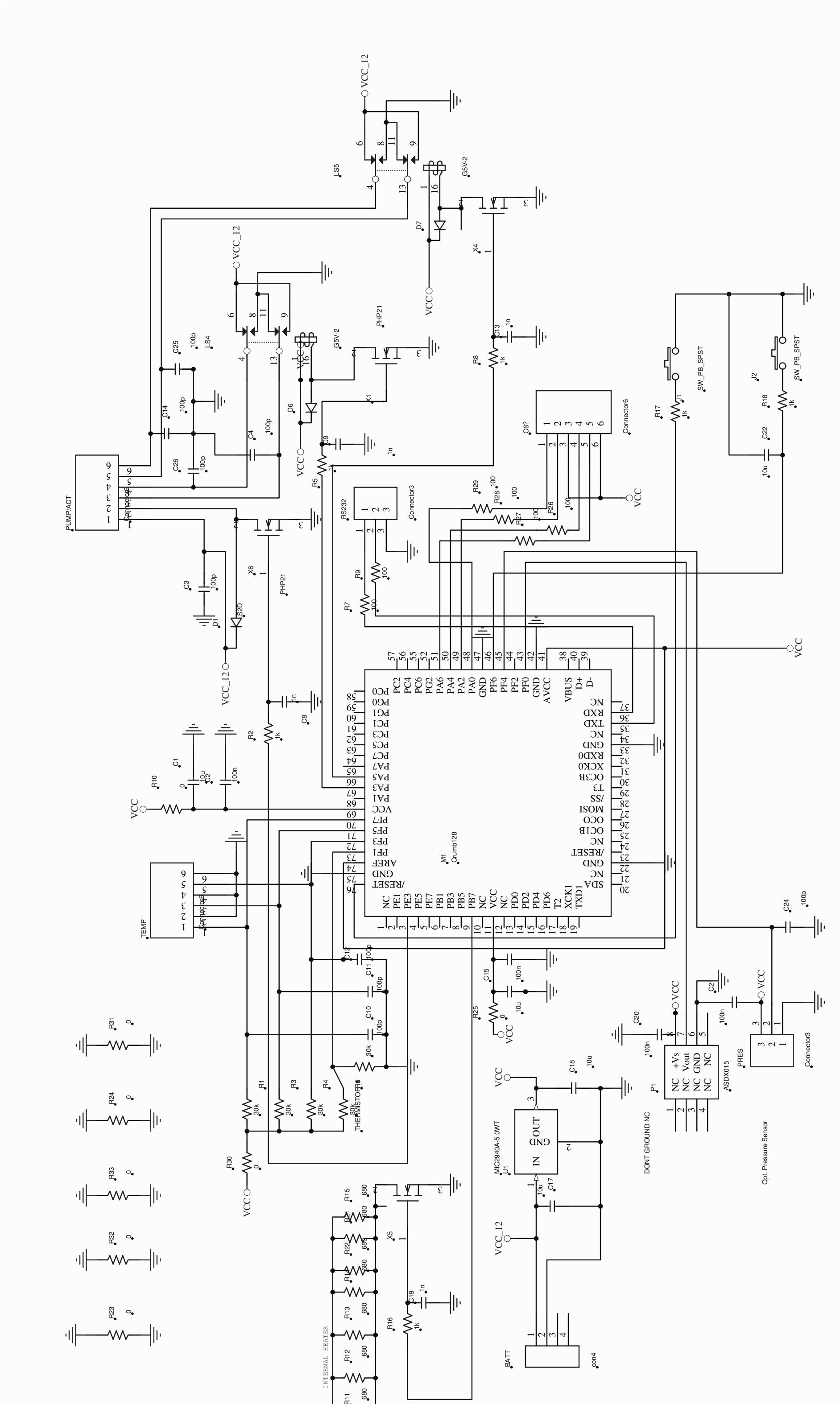


Figure 22: Electronic circuit diagram

A.2 Grounding diagram

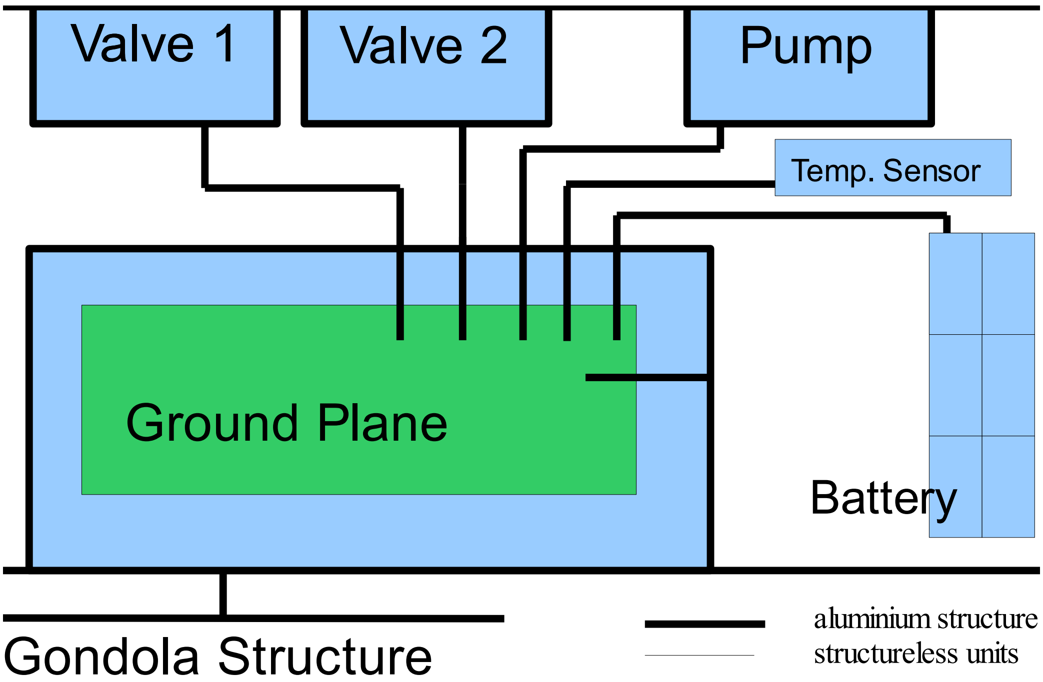
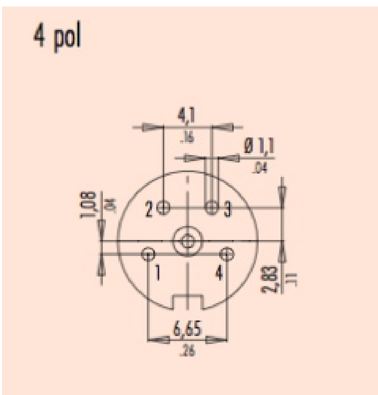
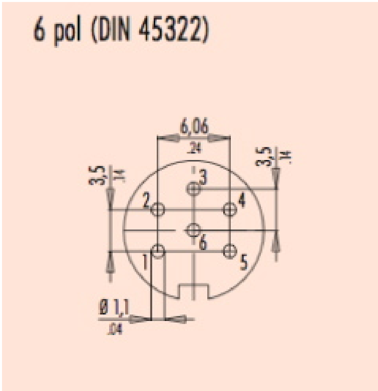
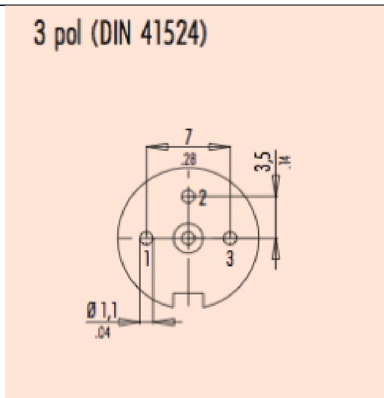
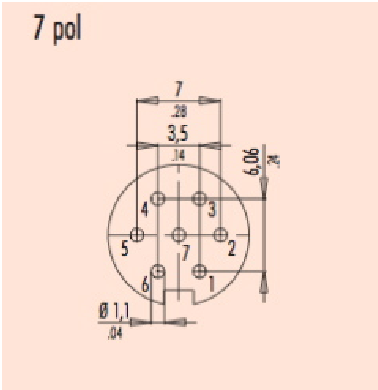
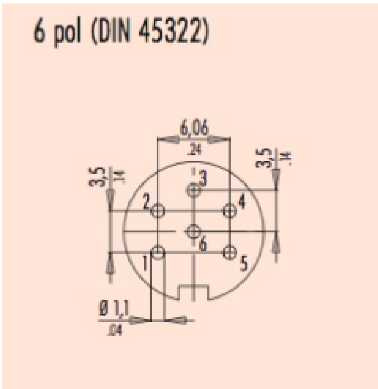


Figure 23: Grounding diagram

A.3 Pin allocation

Interface	# pins	Configuration	Pin Allocation
POW	4		1. V_{cc} (12 V), red 2. GND, blue 3. not used 4. not used

ACT*	6		1. Valve 1 (two way), yellow 2. Valve 1 (two way), purple 3. Valve 2 (three way), green 4. Valve 2 (three way), white 5. GND, blue 6. V_{cc} Pump (12 V), red
RS232	3		1. RX 2. TX 3. GND

TEMP	7 (one unused)		1. Temp Sensor 1, green 2. GND, blue 3. Temp Sensor 2, white 4. GND, blue 5. Temp Sensor 3, purple 6. GND, blue 7. unused
ACT feedback	6		1. Switch 1, Valve 1, blue 2. Switch 2, Valve 1, purple 3. Switch 1, Valve 2, white 4. GND, blue 5. 5V, red 6. Switch 2, Valve2, green

* The pin numbering for the connectors correspond to the pin numbering in the schematics apart from the ACT interface which on the schematics is numbered as follows:

Pin 1 Vcc pump (12 V)

Pin 2 GND

Pin 3/4 Valve 2

Pin 5/6 Valve 1

B Revisions

A table of revisions is shown in table (8).

Date	**Version**	**Changes**
		Preliminary Design Review
2008-04-14	1.0	Initial PDR as delivered to ESA
2008-05-05	1.1	Restructuring and various updates
		Critical Design Review
2008-05-19	1.9	Major restructuring
2008-05-26	2.0	CDR as delivered to IRV
		Mid-term Report
2008-07-28	3.0	All brass components were replaced with stainless steel counterparts. Provisions were made to save more status data in the on-board microcontroller EEPROM (on-board backup). Hardware assembly will start earlier than initially planned. Both the electronics and the battery box are designed to be attached with screws on the back side of each box. Initially, plans had been made for using check-valves that close automatically. Due to concerns about opening those valves in the stratosphere, the team decided to use valves that are actuated only electrically. The team is aware that a power failure can lead to these valves not closing. For vacuum test of valves, for thermal tests and for tests of the PCB, the testing section (13.2) was updated.
		Experiment Acceptance Review
2008-09-19	4.0	Updated mass budget, pin allocations, schematics and website, and removed references to abandoned or changed plans
2008-09-22	4.1	More details on pre-flight procedure, wrote on test results
		Final report
2008-12-17	6.0	Major restructuring, report for IRV
2009-01-15	7.0	Report for ESA/DLR

Table 8: Table of revisions

C Outreach programme

As part of Stratospheric Census the team is aware of the importance of reaching out to the public, educating them about the work carried out by the team.

In an early stage of the project, the team has got in contact with Håkan Sjunnesson, writer for (among others) the Swedish popular science magazine "Ny Teknik" (New Technology), and the project was presented to him.

After flight, a small article appeared in "Kiruna Visionsblad":

Rymdstudenter tackar – och stannar

Rymdstudenterna som fick hjälp, från vänster: Jaroslav Urbar, Tjeckien och framför honom Martin Rudolph, Tyskland, Martin Siegl, Österrike, Mark Fittock, Australien samt Gerrit Holl, Holland.

Fem internationella rymdstudenter genomförde nyligen ett lyckat experiment vid uppsändningen av studentballongen Bexus-7. Med hjälp av ekonomiskt stöd från Progressum hade de byggt en "dammsugare" som under flygningen fångade upp dammpartiklar för analys. I ett pressmeddelande tackar de rymdverksamheterna i Kiruna som samtliga varit ett stöd. De menar att Kiruna är den ideala platsen för rymdstudier och fyra av dem har beslutat sig för att stanna i Kiruna ett år till.

Figure 24: Article in Visionsbladet

Already in the beginning of the project, website was established, following up on a blog, at:

`http://www.stratospheric-census.org`

A screenshot of the website can be seen in figure (25).

Team member Mark Fittock designed a logo for Stratospheric Census. The logo can be seen in figure (26).

In early October 2008, forty stickers, twenty with the experiment logo and twenty with the sponsor logos, were produced by Svenska Wip AB.

Depending on the results, the team may prepare an article to submit for publication to the Journal of Atmospheric and Oceanic Technology by the

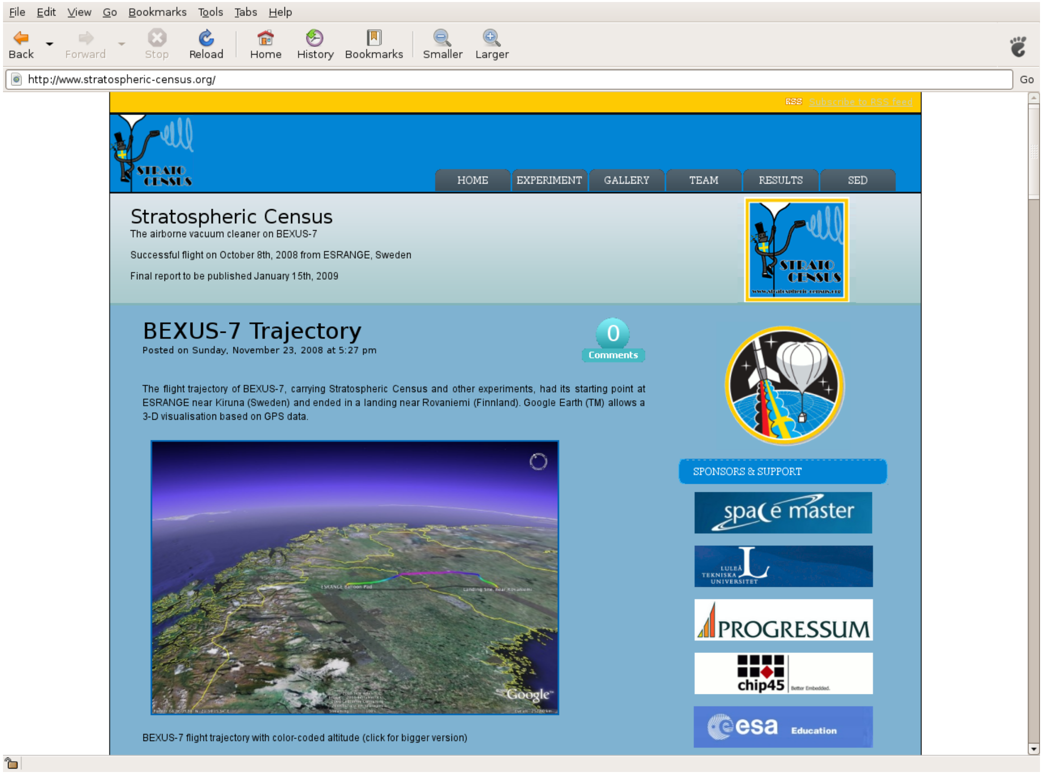


Figure 25: A screenshot of the front page of the website.

American Meteorological Society, intended for “research describing instrumentation and methodologies used in atmospheric (. . .) research, including (. . .) measurement from balloons”.

Additionally, the team would of course be happy to participate in any outreach effort that ESA plans within its own public relations framework.

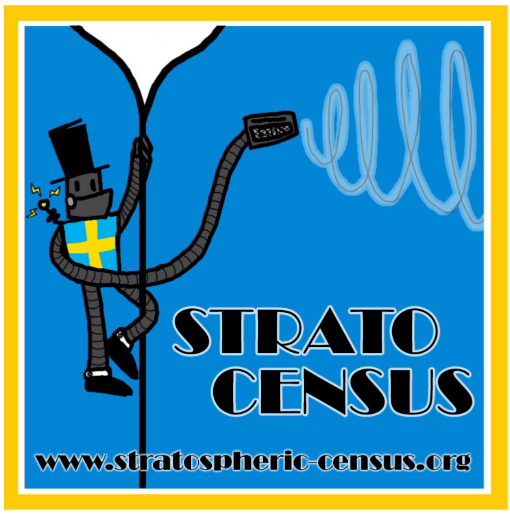


Figure 26: Logo for the Stratospheric Census project

D Full component list

On the following pages are component lists for the financial budget and the mass budget. The power budget is in table (2).

D.1 Financial Budget

The financial budget was kept in Euro, SEK sums were converted as needed. Overall, the expenditures amount to EUR 1833,-. This sum was covered mainly by the Department of Space Science (IRV), by our sponsor PROGRESSUM and by team members themselves. The table on the next page gives detailed insight into costs and how they were covered.

Component	Supplier	Product Number	Qty	Cost / piece	Cost tot (EUR)
Electronics and miscellaneous					
Pressure Sensor	Farnell	ASDX015A24R	1	SEK 561,65	€ 59,12
Thermistor	Farnell	B57540G303J	4	SEK 2,56	€ 1,08
Circular Con. 680, 3 pins, plug	Binder	09 0305 00 03	2	SEK 123,20	€ 25,94
Circular Con. 680, 6 pins, plug	Binder	09 0321 00 06	2	SEK 141,40	€ 29,77
Circular Con. 680, 4 pins, socket	Binder	09-0312-80-04	2	SEK 52,53	€ 11,06
Circular Con. 680, 7 pins, socket	Binder	09-0328-80-07	1	SEK 70,41	€ 7,41
Circular Con. 680, 3 pins, socket	Binder	09-0308-80-03	2	SEK 101,08	€ 21,28
Circular Con. 680, 6 pins, socket	Binder	09-0324-80-06	2	SEK 106,18	€ 22,35
Connector 7 pin	Farnell	09 0325 00 07	1	SEK 76,56	€ 8,06
Connector 4 pin	Farnell	09 0309 00 04	1	SEK 61,98	€ 6,52
Socket 7 pin	Farnell	09 0424 80 07	1	SEK 102,49	€ 10,79
Socket 4 pin	Farnell	09 0412 80 04	1	SEK 79,48	€ 8,37
Voltage Regulator	Farnell	MIC2940A-5.0WT	1	SEK 26,55	€ 2,79
Capacitor 10u	Farnell	GMK325F106ZH-T	10	SEK 1,42	€ 1,49
Capacitor 10u	Farnell	GMK325F106ZH-T	10	SEK 1,42	€ 1,49
Capacitor 100n	Farnell	C1206S104K5RAC	10	SEK 0,87	€ 0,91
MOSFET	Farnell	NDT3055L	7	€ 0,69	€ 4,82
MOSFET	Farnell	IRF5804TRPBF	5	SEK 12,26	€ 6,45
MOSFET	Farnell	IRF5804TRPBF	5	SEK 12,26	€ 6,45
MOSFET	Farnell	PHP21N06LT	5	€ 0,86	€ 4,32
Capacitor 100p	Farnell	B37871K5101J60	20	SEK 0,67	€ 1,41
Capacitor 1n	Farnell	223858115623		SEK 0,54	€ 0,00
Resistor 30k	Farnell	RMC1/8W 1206 1% 30K	50	SEK 0,20	€ 1,05
Resistor	Farnell	MCF 0.25W 0R	50	€ 0,09	€ 4,35
Resistor 1k	Farnell	SR732BTTD1R00F	20	SEK 1,16	€ 2,44
Resistor 100	Farnell	232272461001	50	SEK 0,49	€ 2,58
Alu Box	Farnell	460-0070	1	SEK 242,64	€ 25,54
Alu Box	Farnell	460-0070	1	SEK 242,64	€ 25,54
Relay	Farnell	G5V-2 5DC	2	SEK 21,75	€ 4,58
Relay	Farnell	G5V-2 5DC	1	€ 2,45	€ 2,45
Thermistor	Farnell	B57450G303J	7	€ 0,27	€ 1,91
IC REG LDO	Farnell	MIC2940A-5.0WT	1	€ 2,90	€ 2,90
Resistor 1W 5% 680R	Farnell	MCF 1W 680R	10	SEK 1,02	€ 1,07
Switch, SPNO, flat	Farnell	B3W-4000R	5	SEK 9,47	€ 4,98
Diode	Farnell	S2D	5	SEK 1,62	€ 0,85
Diode	Farnell	S2D	5	SEK 1,62	€ 0,85
Inductor	Farnell	B82422A1102K	10	SEK 6,46	€ 6,80
IC REG LDO	Farnell	MIC2940A-5.0WT	1	SEK 26,55	€ 2,79
Kuhlkörper	Farnell	PF720	5	€ 0,52	€ 2,58
PCB	PCBcart	custom design	2	€ 80,86	€ 161,72
Batteries	Celltech	Saft LSH 20	10	SEK 150,00	€ 157,89
Crumb Board w/ Microcontroller	Chip 45	-	1	€ 0,00	€ 0,00
ISP programmer	Chip 45	-	1	€ 59,95	€ 59,95
CO2 gas bottle	-	-	1	-	-
Actuators & Pump					
Actuator	Airtorque	Er.10.X53S	2	€ 117,00	€ 234,00
Pump	KNF Neuberger	N89KNDC	1	€ 221,46	€ 221,46
Filter					
Elmarco Nanospider	Elmarco	-	6	-	-
Mechanical Components					
Adapter, stainless steel, 1/8'' NPT to 1/8''	Swagelok AT	SS-2-A-2RS	1	€ 8,53	€ 8,53
Anaerobic Thread Sealant	Swagelok AT	MS-PTS-50	1	€ 11,61	€ 11,61
3-way valve, stainless steel	Swagelok AT	SS-42GXF2	1	€ 83,17	€ 83,17
2-way valve, stainless steel	Swagelok AT	SS-42GF2	1	€ 73,84	€ 73,84
Tubing in stainless steel	Swagelok SE	SS-T8-S-083-20E	6	SEK 222,00	€ 140,21
Flat Nuts (M6) for Solectro Frame	Solectro	209021 0003	1	SEK 105,00	€ 11,05
Universalprofil PU25	Solectro	200001 1000	1	SEK 140,00	€ 14,74
Universalprofil PU25	Solectro	200001 1000	1	SEK 140,00	€ 14,74
Bolts (M6)	Elfa	48-471-66	1	SEK 16,54	€ 1,74
Al Flat Beam	Elfa	48-874-02	1	SEK 144,20	€ 15,18
Miscellaneous					
Webspace	Webreus		1	€ 17,98	€ 17,98
Stickers	Svenska Wip AB		1	SEK 300,00	€ 31,58
Cleanbags	TBD				
Shipping, Tax and Customs					
					€ 42,99
					€ 171,70
					€ 23,36
SUM					€ 1832,62

Items	Mass (g)
Frame	1,952.20
Pump	815.30
Control box	730.00
Battery box	609.90
Actuators	1,709.00
Batteries	876.00
Connectors	88.00
Tubing	680.00
Valves	140.00
total	7,600.40

Table 9: The final mass budget for the Stratospheric Census Experiment. A conservative estimate had been 8 kg, allowing for some additions.

E Abbreviations

A list of abbreviations can be seen in table (10).

ACT	Actuator
BAT	Battery
BEXUS	Balloon EXperiments for University Students
BSPP	British Standard Pipe Parallel
CAS	Czech Academy of Sciences
CDR	Critical Design Report or Review
CERN	Centre Europeen de Recherce Nucleaire
CHOUCA	(irradiation chamber/channel type)
CINAA	Coincidence Instrumental Neutron Activation Analysis
COTS	Commercial Off The Shelve
CTU	Czech Technical University
DLR	German Aerospace Centre
EAR	Experiment Acceptance Review
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
Esrange	European Space Range
HPGe	Hyper Pure Germanium detector
IEAP	Institute for Experimental and Applied Physics
ICP-MS ELAN-6000	(type of mass spectrometer)
INP	Institute of Nuclear Physics
IRF	Institut för Rymdfysik (Institute of Space Physics)
IRV	Institut för Rymdvetenskap (Department of Space Science)
LTU	Luleå Tekniska Universitet (Luleå University of Technology)
LVR-15	(irradiation reactor at NRI)
MBU	Microbiological Institute
MISU	Meteorologiska Institutionen Stockholms Universitet
MTR	Mid-Term Report
NPT	National Pipe Thread
NRI	Nuclear Research Institute
PA6	Polyamide type 6
PCB	Printed Circuit Board
PDR	Preliminary Design Report or Review
PE	Polyethylene
PWM	Pulse Width Modulation
SNSB	Swedish National Space Board
SSC	Swedish Space Corporation
TTC	Telemetry, Telecommunications & Command

Table 10: Table of used acronyms

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