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VIRGO

OUTGASSING TEST OF "STORED" ANTISPRING ASSEMBLIES

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In this note we briefly report the outgassing measurements performed of some antispring assemblies which has been stored for several weeks after delivering from the factory. The measurement method is described in detail in the note VACPISA 025.

1 - System performances

The typical base pressure of the test chamber after a baking at 250 ^{0}C for several days is ~10^{-10} mbar, with an outgassing rate of the order of ~10^{-12} mbar l s^{-1} cm^{-2}.

The main components of outgassing after baking are H_2, H_2O, N_2/CO, CO_2. The internal surface of the chamber is 3200 cm^2.

2 - Measurement of the outgassing flow of antisprings

The experimental samples were four antispring assemblies each one consisting of 6 Philips Ferroxdure 330 magnets glued with Vac-Seal to a metal support.

The test was motivated by the fact that the Superattenuator filter under vacuum test at the moment exhibited a strong water vapour outgassing. Possible candidates for such behavior are the antispring assemblies. We have performed another test with antispring assemblies as described in the note VIR-TRE-PIS-142. In that test the antispring assemblies were unpacked just before the test. On the other hand, the antisprings on the filter could have been installed only after several weeks storage. Thus it was necessary to check the effect of storage.

We monitored the evolution of outgassing (time is measured from beginning of the test through the whole paper):

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
28.4	15	3.2×10^{-6}	5.8×10^{-7}	5.2×10^{-5}
97.1	15	1.4×10^{-6}	2.4×10^{-7}	2.3×10^{-5}
147.4	14	9.9×10^{-7}	1.8×10^{-7}	1.6×10^{-5}
169.1	12	9.2×10^{-7}	1.7×10^{-7}	1.5×10^{-5}
194.5	14	8.1×10^{-7}	1.5×10^{-7}	1.3×10^{-5}
267	15	7.0×10^{-7}	1.3×10^{-7}	1.1×10^{-5}
314.5	21	8.8×10^{-7}	1.6×10^{-7}	1.4×10^{-5}
335	11	5.2×10^{-7}	9.1×10^{-8}	8.6×10^{-6}
361.5	19	6.8×10^{-7}	1.2×10^{-7}	1.1×10^{-5}
430.6	12	4.9×10^{-7}	8.7×10^{-8}	8.1×10^{-6}

We quote some relevant numbers for comparison with the other test:

After 4 days at room temperature: $Q = 2.3\text{x}10^{-5}$ mbar l s^{-1}; water vapor ~67%

After 7 days at room temperature: $Q = 1.5\text{x}10^{-5}$ mbar l s^{-1}; water vapor ~71%

Which should be compared to the results of the other test, normalized to 24 magnets:

After 4 days at room temperature: $Q = 2.9\text{x}10^{-5}$ mbar l s^{-1}; water vapor ~53%

After 7 days at room temperature: $Q = 2.2\text{x}10^{-5}$ mbar l s^{-1}; water vapor ~53%

After 4 days at room temperature and a preliminary vacuum baking: $Q = 0.8\text{x}10^{-6}$ mbar l s^{-1}; water vapor ~35%

The water content is larger for this set of antisprings than for the "as delivered" antispring assemblies described in the note VIR-TRE-PIS-3400-142.

The mass spectrum measured after some days pumping at room temperature are shown in Fig. 1. The water content decreased from ~70% to ~60% in a couple of weeks of pumping.

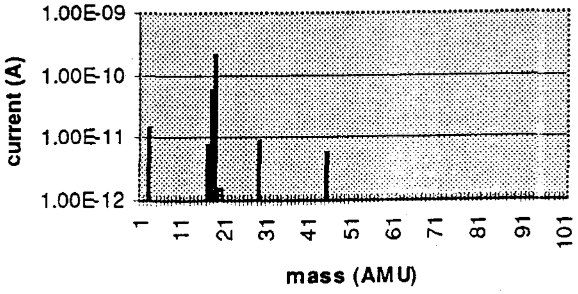

Fig. 1 Outgassing spectrum after some days pumping at room temperature

We heated the samples at 150 ^{0}C for 47 hours and monitored the outgassing:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
431.3	55	$3.2\text{x}10^{-6}$	$6.8\text{x}10^{-7}$	$5.2\text{x}10^{-5}$
478.5	150	$6.1\text{x}10^{-6}$	$7.0\text{x}10^{-7}$	$1.1\text{x}10^{-4}$

The mass spectrum measured during baking is shown in Fig. 2.

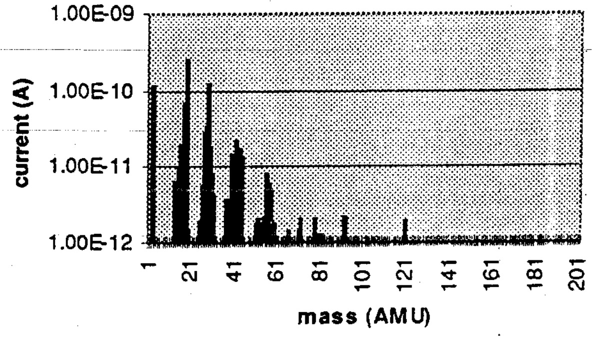

Fig. 2 Outgassing spectrum during baking at 150 °C

Organic fragments appeared but below the level observed for the antisprings described in the note VIR-TRE-PIS-3400-142.
We switched off the heating and we measured:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
501.1	12	1.9×10^{-7}	3.5×10^{-8}	3.1×10^{-6}
599.4	10	1.2×10^{-7}	1.9×10^{-8}	2.0×10^{-6}
646.7	12	1.0×10^{-7}	1.9×10^{-8}	1.6×10^{-6}

The mass spectrum the thermal cycle is shown in Fig. 3.

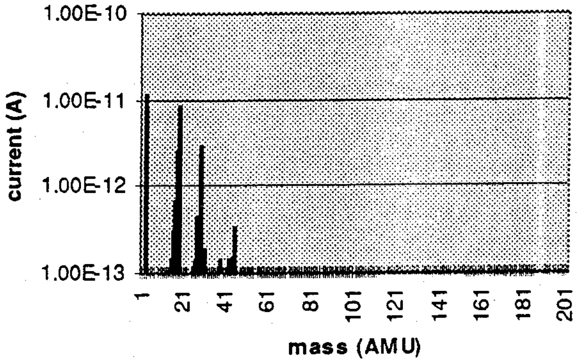

Fig. 3 Outgassing spectrum after the thermal cycle

The outgassing flow evolution is summarized in Fig. 4.

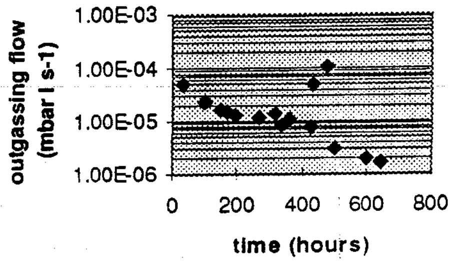

Fig. 4 Time evolution of the outgassing flow

3 - Discussion

The average outgassing flow measured for the four antispring assemblies (accounting for 24 magnets and ~24 cm^2 of Vac-Seal adhesive) after the thermal cycles described above was ~2x10^{-6} mbar l s^{-1}. Some relevant points are the following:

- the outgassing level of the "as delivered" and "stored" antispring assemblies is of the same order
- the "stored" antisprings exhibited a larger water absorption, as could be expected for a long storage inside not hermetically sealed envelopes
- the "stored" antisprings exhibited a smaller organic contamination during baking

The results seem to suggest that the "as delivered" and "stored" antispring assemblies could have been prepared in different ways.

For the above reasons, we strongly recommend another vacuum test on the antispring assemblies.

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UPDATED ESTIMATION OF THE SUSPENSIONS CONTAMINATION BUDGET

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In this note the VIRGO suspensions contamination budget is estimated as deduced from the measurements performed in the Virgo Pisa Vacuum Laboratory. Both the projected outgassing flow and the hydrocarbon partial pressures will be presented.

1 - Superattenuator components

A preliminary investigation of the Superattenuator cascade outgassing has been performed in June 1996 (internal note VACPISA 049). It was shown that the outgassing measurements about components available at that moment allowed to build a Superattenuator cascade with an outgassing flow (~10^{-4} mbar l s^{-1}) one order of magnitude below the one quoted in the Virgo Final Design (~10^{-3} mbar l s^{-1}). The table of June 1996 is reported here for completeness.

Item	*flow (mbar l/s)*
filters	no baking: 3.0×10^{-5} moderate baking: 3.0×10^{-6}
blades	1.7×10^{-5}
magnets	unbaked: 4.3×10^{-5} baked: 8.6×10^{-8}
cabling (Kapton)	1.0×10^{-5}
others	$< 2.0 \times 10^{-6}$

New components have been tested and approved in the last couple of years. A new estimation of the outgassing flow and hydrocarbon pressure will be outlined below.

The main components of the VIRGO suspensions as considered to date (September 1998) are summarised below. Data about motors, cabling, coils, connectors, ferrite magnets, have been supplied by V. Dattilo (VIRGO Pisa); data about marionetta, reference mass and related items have been supplied by P. Rapagnani (VIRGO Roma); data about LVDT and accelerometers have been supplied by R. Stanga (VIRGO Firenze).

- Tower upper part (above conductance plate):
  - Filters: AISI 304 stainless steel
  - Blades: nickel plated steel

  - Magnets: Philips ferrite for the antisprings; CIBAS ferrite for the top stage and accelerometers magnets
  - Cabling: to date Gore-Tex insulation (by Gore) and Kapton insulation (by Axon) ribbons are being considered
  - Connectors: ~100 pieces in each tower; LEMO ones are being considered
  - Coils: Pyre-ML insulation is being considered; used for marionetta steering, LVDTs and accelerometers coils
  - UHV motors: AML motors are being considered
  - Accelerometers: coils and magnets have been included in the above items; electronics consists of peek circuit board plus some resistors/trimmers and capacitors

- Tower upper part (below conductance plate):
  - Marionetta: AISI 304 stainless steel
  - Reference mass: aluminium
  - Mirror magnets: rare-earth magnets from RIAL glued with Vac-Seal to the mirror
  - Cabling
  - Coils for mirror steering: Pyre-ML insulation
  - UHV motors: see above

Data about motors, cabling, coils, ferrite magnets, have been supplied by V. Dattilo (VIRGO Pisa); data about LVDT and accelerometers have been supplied by R. Stanga (VIRGO Firenze); data about marionetta, reference mass and related items have been supplied by P. Rapagnani (VIRGO Roma).

2. Contamination budget

As a first step to ensure good vacuum properties, a good conditioning of components before installation is necessary. The necessary procedures are described in detail in the cleaning note (in preparation) and will only be briefly summarised here. The suggested cleaning procedure is ultrasound bath with a suitable solvent, rinsing and vacuum baking at 150 °C (or the maximum allowable temperature for the component) for a few days. The LIGO experiment has approved a similar procedure for the interferometer components. A peculiar problem of VIRGO as compared to other experiments is the necessity of performing vacuum baking with optical components in situ. Thus a further request for components is the absence of any sizeable contamination during the baking in situ. As much as possible, all components have been tested in typical working conditions and even with strong loads to check the behaviour in the event of malfunctioning. As an example, cabling samples have been supplied with the nominal current values and with huge values during the vacuum test.

The outgassing rate Q and the hydrocarbon partial pressures pp_{HC} for the above mentioned components in various working conditions are summarised below. The reader is referred to the internal notes for the details of each test. We remind that the typical vacuum compatibility test of VIRGO includes raising the temperature up to 50 °C, 100 °C and 150 °C, maintaining each level for a few days. The numbers quoted as the final outgassing rate and hydrocarbon partial pressure are the ones measured after such thermal cycle. We can safely assume that they are the ones to be expected after a several days vacuum baking at 150 °C for component conditioning before installation. The peak values of outgassing rate and hydrocarbon partial pressure measured at some temperature steps are also quoted as an hint to the contamination behaviour during the baking of the lower part of the tower. Some components (mainly inorganic ones) exhibit a final low outgassing rate ($\sim 10^{-10}$ mbar l s^{-1} cm^{-2} or below) together with negligible hydrocarbon contamination at any temperature. In this case no further raising of temperature have been attempted and the values quoted at any temperature above room temperature can be considered as an upper limit to the peak value. Some other components, on the other hand, despite the final low outgassing rate, exhibit sizeable hydrocarbon contamination during some temperature step. It can be reasonably assumed that such components cannot be cleaned completely by the usual procedures, since the contamination problem is more related to the intrinsic material properties than to its history. In this case, an additional raising of temperature is attempted after cooling down to check if the cleaning plus the vacuum baking are effective in assuring a negligible contamination.

We briefly mention the problem of contamination from other sources than hydrocarbons, namely silicone compounds and fluorine compounds. Some space missions data suggest evidence of the contamination from silicone compounds such as epoxy adhesives. On the other hand, semiconductor industries have triggered the development of Teflon-like materials with low fluorine outgassing for the same reasons. At the moment, there is no consensus about the levels which could harmful in the context of the laser interferometer gravitational wave detectors. The basic attitude seems to be keeping such types of contamination at the lowest possible levels.

The relevant outgassing data are summarised in Table 1 for the tower upper part and in Table 2 for the tower lower part. The exposed area for each homogeneous component is presented. For composite pieces such as motors or connectors, the total number per tower is quoted and the data in the columns of outgassing rate should be read as outgassing flow data.

Symbol explaination:
- A is the exposed area
- N is the number of pieces for composite items
- Q is the outgassing rate measured in mbar l s^{-1} cm^{-2}
- pp_{HC} is the hydrocarbon partial pressure measured using the above criterion
- Φ is the outgassing flow measured in mbar l s^{-1}
- index 1 labels the values after the vacuum baking described above;
- index 2 labels the peak value attained during vacuum baking
- NG is used for negligible
- NA is used for not available data
- Cabling G means Gore-Tex cabling
- Cabling K means Axon Kapton cabling
- $^{(*)}$ means that the quoted number should be read as outgassing flow and not outgassing rate

Some useful notes for data interpretation:
- Filters: the material is AISI 304 stainless steel; the data are commonly cited values for unbaked and moderately baked material
- Vac-Seal: it has been assumed that each magnet involves ~1 cm^2 of exposed glue surface (on the bottom and on the top)
- Coils: it has been assumed that the exposed surface is the exterior surface plus 10% of the total wiring surface; it is known that is possible to pump out trapped air inside a coil and it seems reasonable to assume that only some part
- EC: electronics components for accelerometers, to be defined

ITEM	A	N	Q_1	pp_{HC1}	Q_2	pp_{HC2}	Φ_1	Φ_2
Filters	7.0+4	unbaked	1.0-10	NG			7.0-6	
		baked	1.0-11	NG			7.0-7	
Blades	1.6+4		4.0-10	2.1-11	4.0-9(2)	2.5-8(2)	6.4-6	6.4-5
					1.8-7(3)	3.4-8(3)	6.4-6	2.9-3
Magnets (Phillips)	1.8+4		7.6-11	1.7-10	4.0-7(2)	3.9-7(2)	1.4-6	7.2-3
Magnets (Cibas)	5.0+2		1.7-11	1.6-13	1.3-5(2)	7.5-5(2)	8.5-9	6.5-3
					3.0-8(3)	1.1-7(3)	8.5-9	1.5-5
					5.4-10(5)	1.3-12(5)	8.5-9	2.7-7
Motors(*)		22	1.0-8	1.0-12	1.7-7(1)	1.0-10(1)	2.2-7	3.7-6
					1.7-6(3)	1.0-9(3)	2.2-7	3.7-5
Cabling G	2.5+5		2.0-12	NG	2.8-8(3)	NG	4.4-7	7.0-3
Cabling K	2.5+5		8.0-12	7.4-12	1.2-8(2)	4.5-7(2)	2.0-6	3.0-3
					1.3-8(3)	8.9-7(3)	2.0-6	3.2-3
					5.8-10(5)	2.3-8(5)	2.0-6	1.4-4
Connectors(*)		100	1.0-9	9.0-12	2.2-5(2)	2.2-7(2)	1.0-7	4.3-7
					1.8-8(4)	6.0-10(4)	1.0-7	1.8-6
					1.2-5(3)	2.2-7(3)	1.0-7	1.2-3
					1.7-7(5)	6.2-9(5)	1.0-7	1.7-5
Coils	2.6+4		8.4-11	2.5-14	1.1-8(2)	1.4-9(2)	2.2-6	2.9-4
Vac-Seal	5.0+2		5.6-10	7.5-11	2.7-5(3)	1.8-6(3)	2.8-7	1.4-2
EC	NA	NA	NA	NA	NA	NA	NA	NA

Table 1 Contamination budget of the tower upper part;
(1) means at 80°C; (2) means at 100°C; (3) means at 150°C;
(4) means at 80°C, second heating; (5) means at 150°C, second heating

ITEM	A	N	Q_1	pp_{HC1}	Q_2	pp_{HC2}	Φ_1	Φ_2
Marionetta	5.0+3	unbaked	1.0-10	NG			5.0-7	
		baked	1.0-11	NG			5.0-8	
Reference mass	6.3+3	unbaked	1.0-10	NG			6.3-7	
		baked	1.0-11	NG			6.3-8	
Magnets (Rial)	13.		NA	NA	NA	NA	NA	NA
Coils	6.5+3		8.4-11	2.5-14	1.1-8$^{(2)}$	1.4-9$^{(2)}$	5.5-7	7.2-5
Motors$^{(*)}$		1	1.0-8	1.0-12	1.7-7$^{(1)}$	1.0-10$^{(1)}$	1.0-8	1.7-7
					1.7-6$^{(3)}$	1.0-9$^{(3)}$	1.0-8	1.7-6
Vac-Seal	4.0		5.6-10	7.5-11	2.7-5$^{(3)}$	1.8-6$^{(3)}$	2.2-9	1.1-4

Table 2 Contamination budget of the tower lower part; for symbols refer to the other caption

3 - Conclusions

As can be deduced from the tables above, it is possible to build a suspension system with a contamination budget with an overall outgassing flow of ~10^{-5} mbar l s^{-1}, two order of magnitudes below the FD constraints, if proper components and proper cleaning and conditioning procedures are selected.

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OUTGASSING TEST OF UMBRA CUSCINETTI BEARING CAGES

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VIR-TRE-PIS-3400-130

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Approved by:		

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In this note we briefly report the outgassing measurements performed on the cages of the bearings from Umbra Cuscinetti. The measurement method is described in detail in VACPISA 025.

1 - System performances

We performed a baking of the test chamber at 250 ^{0}C for several days achieving a final base pressure of ~10^{-10} mbar.

The main components of outgassing after baking were H_2, H_2O, N_2/CO, CO_2. The internal surface of the chamber is 3200 cm^2.

2 - Measurement of the outgassing rate of bearings

The experimental samples were three cages for bearings manufactured by Umbra Cuscinetti, Italy. The nominal material was polyimide. The cages have been cleaned with an ultrasound bath of isopropyl alcohol for 40 minutes and a few hours baking in air at 100 ^{0}C.

We monitored the evolution of outgassing (time is measured from beginning of the test through the whole paper):

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
1.0	25	1.7×10^{-5}	2.0×10^{-6}	3.0×10^{-4}
18.5	25	3.3×10^{-6}	4.3×10^{-7}	5.7×10^{-5}
23	25	2.8×10^{-6}	3.6×10^{-7}	4.9×10^{-5}
40.5	25	1.7×10^{-6}	2.2×10^{-7}	3.0×10^{-5}
112.5	25	7.0×10^{-7}	9.0×10^{-8}	1.0×10^{-5}
143	25	5.7×10^{-7}	7.3×10^{-8}	9.9×10^{-6}
162	25	3.3×10^{-7}	4.0×10^{-8}	5.8×10^{-6}

The mass spectrum after 162 hours is shown in Fig. 1.

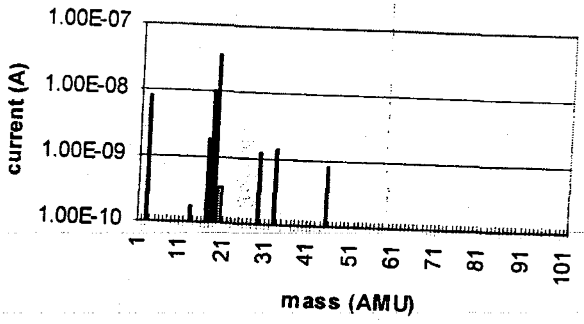

Fig. 1 Outgassing spectrum after 162 hours pumping at room temperature

We set temperature at 50 ^{0}C for 167 hours and monitored the evolution of outgassing:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
163	53	2.3×10^{-6}	3.0×10^{-7}	4.0×10^{-5}
163.5	52	5.1×10^{-6}	7.0×10^{-7}	8.8×10^{-5}
168	54	3.7×10^{-6}	5.2×10^{-7}	6.4×10^{-5}
185	52	1.7×10^{-6}	1.9×10^{-7}	3.0×10^{-5}
193	49	1.2×10^{-6}	1.6×10^{-7}	2.1×10^{-5}
212	50	7.9×10^{-7}	1.0×10^{-7}	1.4×10^{-5}
218	49	6.7×10^{-7}	8.6×10^{-8}	1.2×10^{-5}
304.5	48	1.8×10^{-7}	1.9×10^{-8}	3.2×10^{-6}
307	48	1.5×10^{-7}	1.6×10^{-8}	2.7×10^{-6}
330	47	2.6×10^{-7}	2.7×10^{-8}	4.7×10^{-6}

The mass spectrum at 330 hours is shown in Fig. 2.

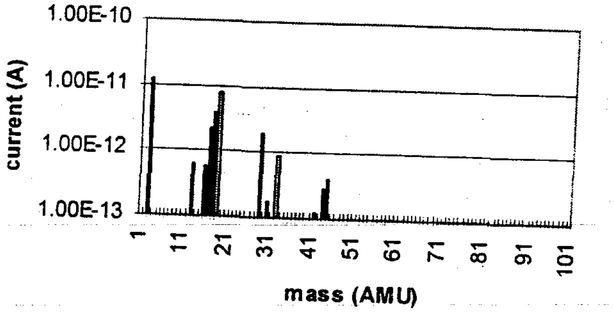

Fig. 2 Outgassing spectrum after 167 hours at 50 ^{0}C

We set temperature at 100 ^{0}C for 222 hours and monitored the evolution of outgassing:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
330.25	77	5.0×10^{-7}	5.6×10^{-8}	8.9×10^{-6}
330.5	110	6.8×10^{-6}	7.5×10^{-7}	1.2×10^{-4}
330.75	96	2.2×10^{-6}	2.8×10^{-7}	3.8×10^{-5}
331	96	1.8×10^{-6}	2.4×10^{-7}	3.1×10^{-5}
337	100	1.2×10^{-6}	1.4×10^{-7}	2.1×10^{-5}
355	100	1.5×10^{-6}	1.9×10^{-7}	2.6×10^{-5}
361	100	4.2×10^{-7}	3.7×10^{-8}	7.7×10^{-6}
379	100	2.2×10^{-7}	2.1×10^{-8}	4.0×10^{-6}
449	100	3.6×10^{-7}	4.8×10^{-8}	6.2×10^{-6}
474	100	2.7×10^{-7}	3.5×10^{-8}	4.7×10^{-6}
523	100	2.8×10^{-7}	3.4×10^{-8}	4.9×10^{-6}
552	100	2.5×10^{-7}	2.8×10^{-8}	4.4×10^{-6}

The mass spectrum after 31 hours at 100 ^{0}C is shown in Fig. 3.

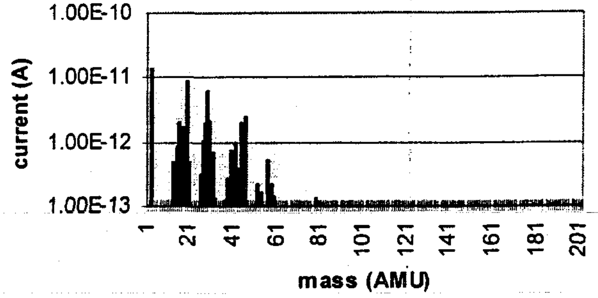

Fig. 3 Outgassing spectrum after 31 hours at 100 ^{0}C

Some organic fragments appear, particularly at masses 41, 43, 45, 53, 55, 57. The fragments are still present after 144 hours at 100 ^{0}C, and some higher mass fragments have appeared.

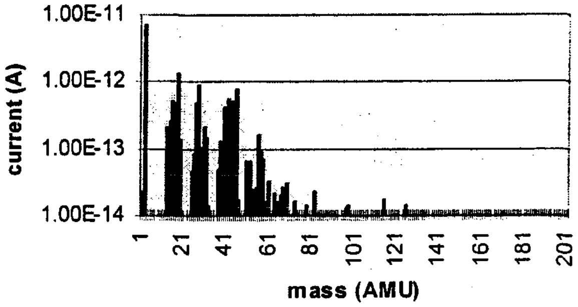

Fig. 4 Outgassing spectrum after 144 hours at 100 ^{0}C

We set temperature at 150 ^{0}C for 113 hours and monitored the evolution of outgassing:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
552	120	$4.6\text{x}10^{-7}$	$5.2\text{x}10^{-8}$	$8.2\text{x}10^{-6}$
552.25	154	$2.3\text{x}10^{-5}$	$2.0\text{x}10^{-6}$	$4.2\text{x}10^{-4}$
552.5	150	$1.0\text{x}10^{-5}$	$8.5\text{x}10^{-7}$	$1.8\text{x}10^{-4}$
552.75	150	$8.8\text{x}10^{-6}$	$6.8\text{x}10^{-7}$	$1.6\text{x}10^{-4}$
553	150	$8.4\text{x}10^{-6}$	$6.7\text{x}10^{-7}$	$1.6\text{x}10^{-4}$
553.5	150	$7.6\text{x}10^{-6}$	$6.1\text{x}10^{-7}$	$1.4\text{x}10^{-4}$

617	150	1.3×10^{-6}	5.5×10^{-7}	1.5×10^{-5}
665	150	1.7×10^{-6}	1.2×10^{-7}	3.2×10^{-5}

The mass spectrum measured after 2 hours at 150 ^{0}C is shown in Fig. 5.

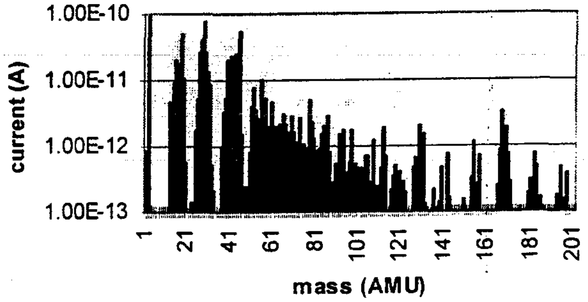

Fig. 5 Outgassing spectrum after 2 hours at 150 ^{0}C

We note the presence of clusters centred at multiples of mass 14, typical of organic contamination. There are still some fragments after 113 hours at 150 ^{0}C as shown in Fig. 6.

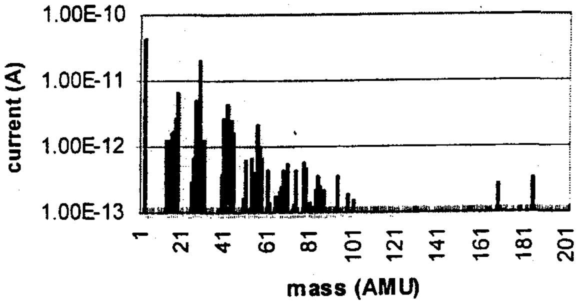

Fig. 6 Outgassing spectrum after 113 hours at 150 ^{0}C

We switched off the heating and we measured:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
742	15	2.3×10^{-7}	5.0×10^{-8}	3.6×10^{-6}

785	15	$9.3x10^{-8}$	$6.2x10^{-9}$	$1.7x10^{-6}$
787	15	$3.9x10^{-8}$	$5.0x10^{-9}$	$6.8x10^{-7}$

The mass spectrum at 787 hours is shown in Fig. 7.

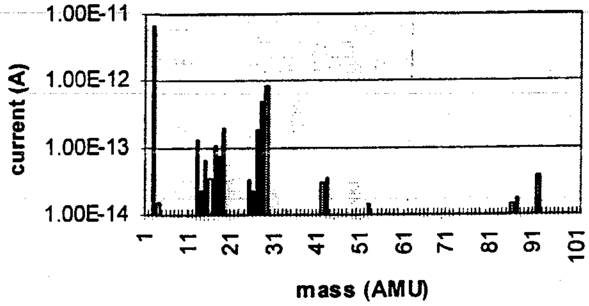

Fig. 7 Outgassing spectrum after the first thermal cycle

Since some organic contamination was present during the various steps in temperature, we checked if it had been removed by the thermal cycle. We heated the samples at 80 ^0C for 169 hours:

t(h)	$T(^0C)$	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
787.25	51	$4.9x10^{-8}$	$1.5x10^{-8}$	$6.8x10^{-7}$
787.5	90	$9.9x10^{-8}$	$3.1x10^{-9}$	$1.8x10^{-6}$
787.75	76	$1.4x10^{-7}$	$8.4x10^{-9}$	$2.6x10^{-6}$
788	84	$2.1x10^{-7}$	$1.1x10^{-8}$	$4.0x10^{-6}$
788.5	78	$4.7x10^{-7}$	$1.8x10^{-8}$	$9.0x10^{-6}$
789	78	$9.1x10^{-7}$	$2.9x10^{-8}$	$1.8x10^{-5}$
789.5	83	$1.0x10^{-6}$	$3.6x10^{-8}$	$1.9x10^{-5}$
790	77	$8.5x10^{-7}$	$3.1x10^{-8}$	$1.6x10^{-5}$
790.5	81	$6.0x10^{-7}$	$2.8x10^{-8}$	$1.1x10^{-5}$
791.5	81	$2.5x10^{-7}$	$2.0x10^{-8}$	$4.6x10^{-6}$
793	81	$1.9x10^{-7}$	$1.3x10^{-8}$	$3.5x10^{-6}$
809.5	84	$3.9x10^{-8}$	$4.1x10^{-9}$	$6.0x10^{-7}$
811	77	$9.4x10^{-8}$	$8.4x10^{-9}$	$1.7x10^{-6}$
834	80	$3.1x10^{-7}$	$3.5x10^{-8}$	$5.5x10^{-6}$

A spectrum taken at 834 hours is shown in Fig. 8. Some fragments at Some fragments at 41, 43 and 55 are evident.

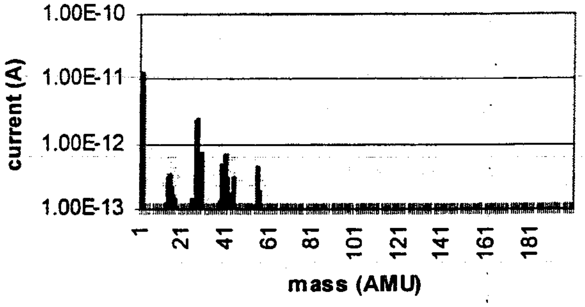

Fig. 8 Outgassing spectrum during the second heating at 80 ^{0}C

We switched off and we started heating again, first at 80 ^{0}C then at 150 ^{0}C:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
882.5	14	$2.0\text{x}10^{-8}$	$2.6\text{x}10^{-9}$	$3.5\text{x}10^{-7}$
883.5	83	$3.2\text{x}10^{-8}$	$3.2\text{x}10^{-9}$	$5.8\text{x}10^{-7}$
884.5	136	$1.7\text{x}10^{-7}$	$2.7\text{x}10^{-8}$	$2.9\text{x}10^{-6}$
886.5	152	$5.6\text{x}10^{-7}$	$6.0\text{x}10^{-8}$	$1.0\text{x}10^{-5}$
1002.5	152	$5.8\text{x}10^{-6}$	$2.0\text{x}10^{-7}$	$1.1\text{x}10^{-4}$
1050.5	152	$2.7\text{x}10^{-6}$	$2.3\text{x}10^{-7}$	$4.9\text{x}10^{-5}$
1144.5	152	$2.2\text{x}10^{-7}$	$2.0\text{x}10^{-8}$	$4.0\text{x}10^{-6}$

The spectrum taken at 1050.5 hours is shown in Fig. 9. Some organic fragments have appeared again.

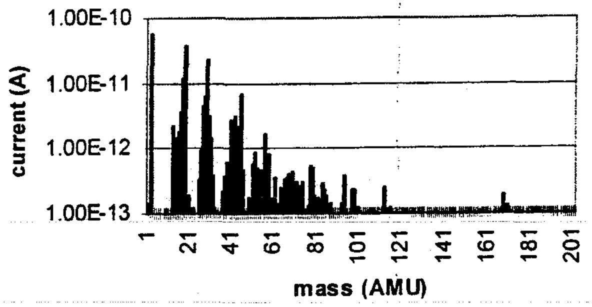

Fig. 9 Outgassing spectrum during the third heating

We switched off heating and we measured:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
1147	132	$1.3\text{x}10^{-7}$	$1.1\text{x}10^{-8}$	$2.4\text{x}10^{-6}$
1175	15	$1.2\text{x}10^{-8}$	$1.4\text{x}10^{-9}$	$2.1\text{x}10^{-7}$
1176.5	15	$2.8\text{x}10^{-8}$	$2.2\text{x}10^{-9}$	$5.2\text{x}10^{-7}$
1194	15	$6.3\text{x}10^{-9}$	$7.1\text{x}10^{-10}$	$1.1\text{x}10^{-7}$
1200	20	$5.9\text{x}10^{-9}$	$6.2\text{x}10^{-10}$	$1.1\text{x}10^{-7}$
1219	14	$4.6\text{x}10^{-9}$	$6.8\text{x}10^{-10}$	$7.9\text{x}10^{-8}$

A spectrum taken at 1219 hours is shown in Fig. 10.

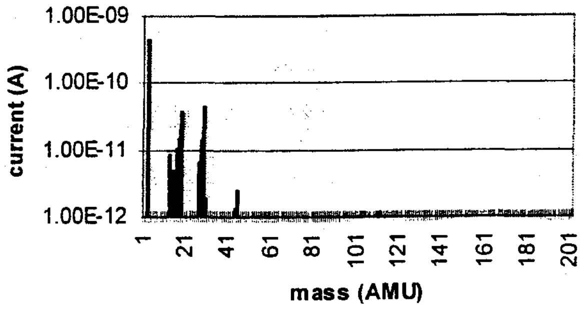

Fig. 10 Outgassing spectrum during the second cooling down

After the two thermal cycles described above we tried to ramp temperature to 80 ^{0}C again in steps of 20 ^{0}C/h:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
1218.5	45	$6.9x10^{-9}$	$7.8x10^{-10}$	$1.2x10^{-7}$
1219.5	58	$1.2x10^{-8}$	$1.3x10^{-9}$	$2.1x10^{-7}$
1222	84	$1.9x10^{-8}$	$2.0x10^{-9}$	$3.4x10^{-7}$
1297	83	$1.7x10^{-8}$	$1.9x10^{-9}$	$3.0x10^{-7}$
1320	78	$1.1x10^{-8}$	$1.0x10^{-9}$	$2.0x10^{-7}$
1338	83	$1.0x10^{-8}$	$1.6x10^{-9}$	$1.7x10^{-7}$

The spectrum at 1297 hours is shown in Fig. 11. Some organic fragments do appear again.

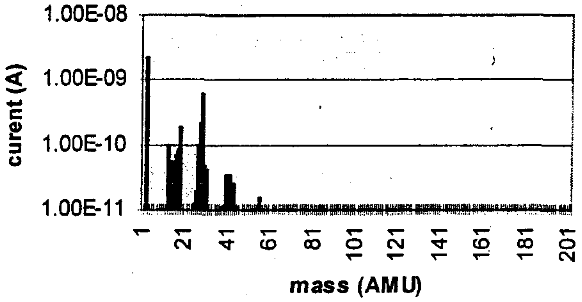

Fig. 11 Outgassing spectrum during the fourth baking

We switched off heating and we measured:

t(h)	T(^{0}C)	p_1(mbar)	p_2(mbar)	Q(mbar l/s)
1338.5	57	$3.9x10^{-9}$	$5.4x10^{-10}$	$6.7x10^{-8}$
1341	35	$4.5x10^{-9}$	$5.0x10^{-10}$	$8.0x10^{-8}$
1341.5	32	$5.0x10^{-9}$	$5.4x10^{-10}$	$8.9x10^{-8}$
1344	28	$4.8x10^{-9}$	$5.1x10^{-10}$	$8.6x10^{-8}$
1368	15	$1.4x10^{-9}$	$2.3x10^{-10}$	$2.3x10^{-8}$
1393	15	$2.0x10^{-9}$	$4.7x10^{-10}$	$3.1x10^{-8}$

1357.5	15	$9.8x10^{-10}$	$2.1x10^{-10}$	$1.5x10^{-8}$
1482	15	$7.7x10^{-10}$	$1.7x10^{-10}$	$1.2x10^{-8}$
1655	15	$1.9x10^{-9}$	$3.3x10^{-10}$	$3.1x10^{-8}$
1681	15	$1.5x10^{-9}$	$2.8x10^{-10}$	$2.4x10^{-8}$
1699	15	$1.2x10^{-9}$	$2.3x10^{-10}$	$1.9x10^{-8}$

The spectrum measured at the end of cooling is shown in Fig. 12.

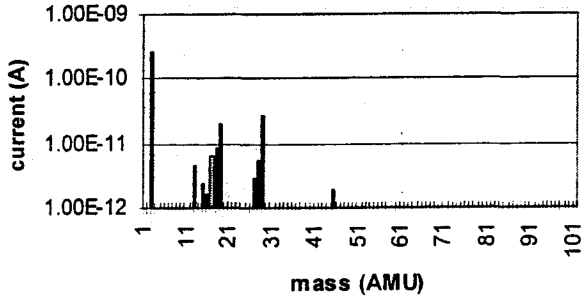

Fig. 12 Outgassing spectrum after the last cooling

The outgassing rate evolution is summarized in Fig. 13.

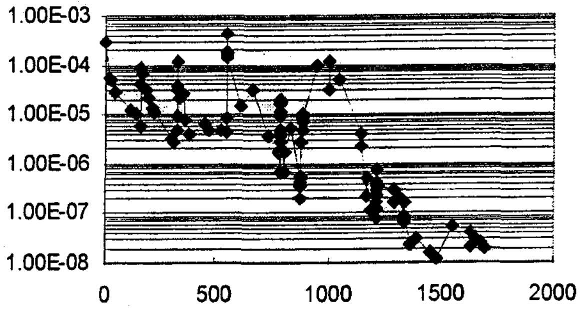

Fig. 13 Time evolution of the outgassing rate

3 - Discussion

The outgassing flow measured for the three cages after the various thermal cycles was ~10^{-8} mbar l s^{-1}. The various thermal cycles were not able to completely remove the organic contaminants, which appear again any time the cages are heated, even at 80 ^{0}C. Moreover, the composition of mass spectrum suggests the presence of polyamide in the cage composition. At a visual inspection, we observed that the color of the cages was slightly changed at the end of the test. During the test we had to degas gauges several times because of contamination. After the test the chamber was very contaminated. An orange contaminant layer was found on the chamber diaphragm were cages have been posed during the test. In a further investigation we discovered a similar contamination on the opposite diaphragm side (facing the pump) as well.