

OUTGASSING TESTS ON IRAS SOLAR PANEL SAMPLES

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1. INTRODUCTION

1.1 Purpose

The IRAS satellite (InfraRed Astronomical Satellite) is a joint venture between the Netherlands, United States and the United Kingdom to investigate the infrared sources in space by means of a telescope, which is cooled to superfluid helium temperature (about $+ 2 - 10\text{K}$).

Due to the low operation temperature the risks of contamination, particularly of the optical components, are high.

The efforts to diminish the contamination hazard to a minimum include selection of low outgassing materials, special treatment after manufacturing and special spacecraft handling procedures. All the constituting materials of the satellite are potential sources of contamination. Due to their location, their relatively high temperature and the many organic materials contained, the solar panels require special consideration.

At the request of Fokker, prime contractor for the IRAS project and manufacturer of the solar panels, the Materials Section of ESTEC carried out several outgassing tests on representative solar panel samples with a view to determining the extent of contamination that could be expected from this source.

1.2 Purpose of tests carried out in ESTEC

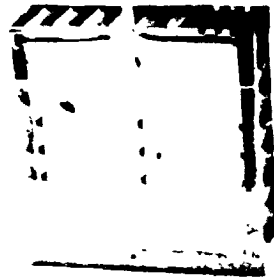
The materials for the construction of the solar panels have been selected as a result of contamination obtained in "Micro VCM" tests. This method is a "screening test" and gives only the "qualified" or "non-qualified" results according to criteria used by NASA as well as by ESA (1% TMI and 0.1% CVCM).

This test method is intended to provide an accelerated means of determining the total mass loss of materials and their contamination attributes in exposure to vacuum ($< 10^{-6}$ torr) at a temperature of 125°C . This method might give misleading results in case of those materials, whose outgassing kinetics at 125°C are different from those at the temperature of intended use.

The comparison of materials properties is only valid at 125°C . The measurement for collectors at 25°C with similar sticking coefficients. It is considered, however, that the method of using the defined screening operation is a conservative one. The risk is that a few materials which have acceptable properties (at the intended temperature of use) will be eliminated because their properties are not satisfactory at the test temperature of 125°C . It was, however, necessary to know the kinetics of outgassing (i.e. total mass loss of materials and

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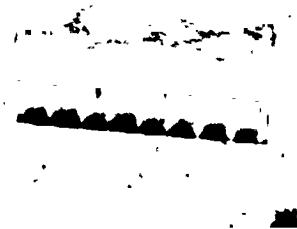
1a



1b



1c



1d

Figure 1

condensable volatile materials coming from selected products versus time, temperature of solar panels and different temperature configurations of telescope) to determine the contamination risks during the mission of the satellite.

2. DESCRIPTION OF SAMPLES

The six test samples have been manufactured like solar panels of a flight model (Figure 1).

3. DESCRIPTION OF TEST EQUIPMENT

The equipment developed at ESTEC to perform the outgassing measurements makes use of the advantages offered combining QCMs (Quartz Crystal Balance) with a conventional vacuum balance. This system (Figure 2) consists of a Sartorius 4201 vacuum balance with magnetically suspended sample hangers.

The balance has a sensitivity of 1×10^{-5} g, but due to the vibrations as well as temperature and humidity variations in laboratories, the accuracy is limited to 1×10^{-4} g. The maximum load of the balance is 25 g and the temperature is controlled by an oven containing the samples.

The three Celesco QCMs can measure the amount of materials condensed on the exposed crystal down to a few times 10^{-8} g/cm² (sensitivity given by the manufacturer: 8.9×10^{-9} g/cm²/mV⁻¹ output).

These QCMs can be cooled down from an ambient temperature to liquid nitrogen temperature.

The condenser plate (with holes in front of QCMs) is also controlled at the lowest QCM temperature and has a diameter of 146 mm (area ± 175 cm²). The contaminants trapped on the plate can be collected for analysis (i.e. infrared spectroscopy).

The pumping system is a Varian VT102 ion pump system, equipped with a quadrupole mass spectrometer permitting analysis of outgassing products which do not condense on the condenser plate (i.e. mainly water, solvents and atmospheric gases). Also pressures down to at least 10^{-9} torr can be obtained.

VBQC-1 OUTGASSING SYSTEM

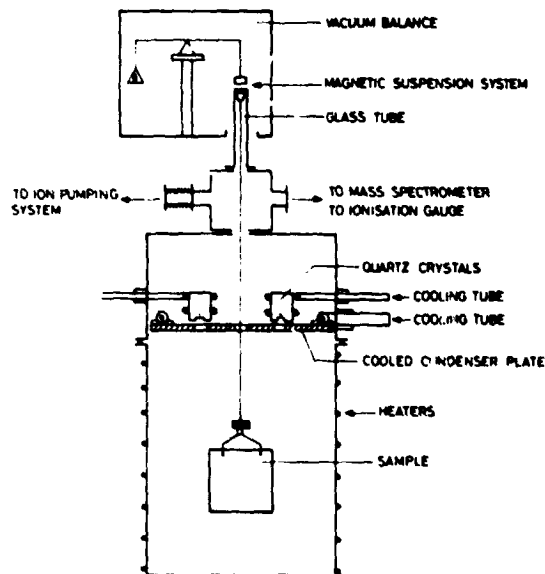


Figure 2

4. SAMPLE PREPARATION

Each sample has been conditioned for at least 24 hours at a standard temperature of 20°C and a standard humidity of 65% before evacuating the test chamber and starting the test. This is similar to the conditioning used in the Micro VCM procedure (PSS-02T).

- a. Clean the QCMs and cooled plate with a mixture of IPA and freon TF (50%-50%).
- b. Mount the sample on vacuum balance and switch on.
- c. Close the oven.
- d. Pump down.
- e. Cool the QCMs and cooled plate to the intended temperature when the pressure is about 10^{-4} torr.
- f. When the QCMs and cooled plate temperatures are correct, start heating the oven.

In the normal sequence of operations, there was a minimum time between the actions; however, in some cases the time between the actions increased due to pumping failure, cooling failure, stabilization, etc. (see Table 1).

For the tests 1046/1047 and 1049 the cooling of the QCMs and heating of the sample have been started together under dry nitrogen at atmospheric pressures before pump down. The QCMs and the condensor plate are maintained at temperature as described in Table 2. Through the choice of these temperatures, a discrimination can be made between outgassing products with respect to their vapor pressure. The composition of the lightest fractions has been analyzed using a mass spectrometer in the pumping line.

5. MASS SPECTROMETER DATA

The analysis of gases coming out of samples has been carried out with a quadruple spectrometer (see Table 3). This analysis has only been carried out with the experiment 1042 (sample 3) because of failure of the spectrometer.

5.1 Infrared analysis of contaminants trapped on cooled plate

After each test the composition of the organic products condensed on the cooled plate have been analyzed by infrared spectrometry method. The results are shown in Table 4.

6. METHODS OF CALCULATION

The different parameters were collected continuously on six channels recorder and the recordings were analyzed by hand to measure the signal V.

- a. In mV for the total mass loss versus time.
- b. In mV for volatile condensables versus time.

The TML is calculated according to the following formula:

$$\% \text{ TML} = \frac{V(\text{atm} + V \text{ buoyancy effect} - V_t) \times S}{M_o} \times 100$$

where:

V atm = signal at atmospheric pressure

V = buoyancy effect *

Vt = signal during test versus time

S = sensitivity $10^{-4} \text{ g mV}^{-1}$

Mo = initial weight before testing.

The CVCM is calculated according to the formula:

$$\% \text{ CVCM} = \frac{(V_t - V_o) \times 8.86 \times 10^{-9} \times 175}{M_o} \times 100$$

where:

Vo = signal at time o **

Vt = signal during test versus time

$8.86 \times 10^{-9} \text{ g/cm}^{-2} / \text{mV}^{-1}$ = sensitivity of QCMs (given by manufacturer)

175 cm^2 = area of condensor plate

Mo = initial weight of sample before test in grammes.

These data are listed and stored in the computer for calculations.

* buoyancy effect = buoyancy of balance + buoyancy of sample
(not including the air contained in the sample).

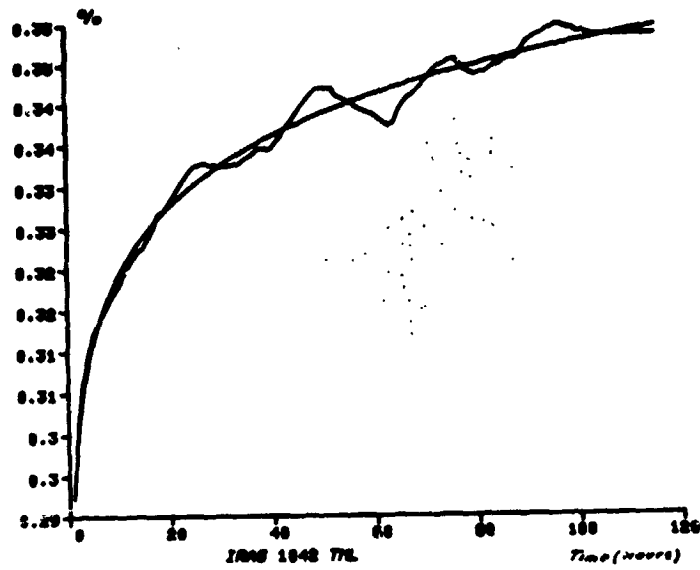
** Vc = the lowest signal observed after heating the sample.

The time zero has been taken from the heating of the sample for the first four tests and at pump down time for the other three tests.

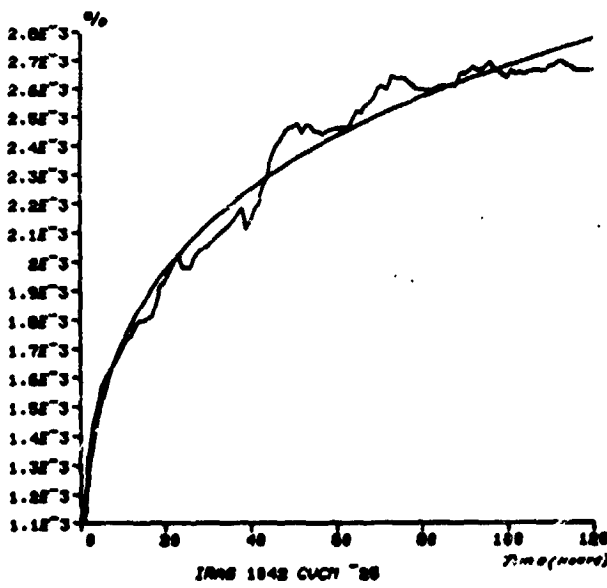
The zero value of the total mass loss has been measured from the initial signal of vacuum balance as soon as the sample was mounted corrected from the buoyancy effect measured after each test.

Due to vibrations of the vacuum balance during the mounting of the sample and the pump down, the measurement of buoyancy effect is very difficult and an error of a few mg can be done.

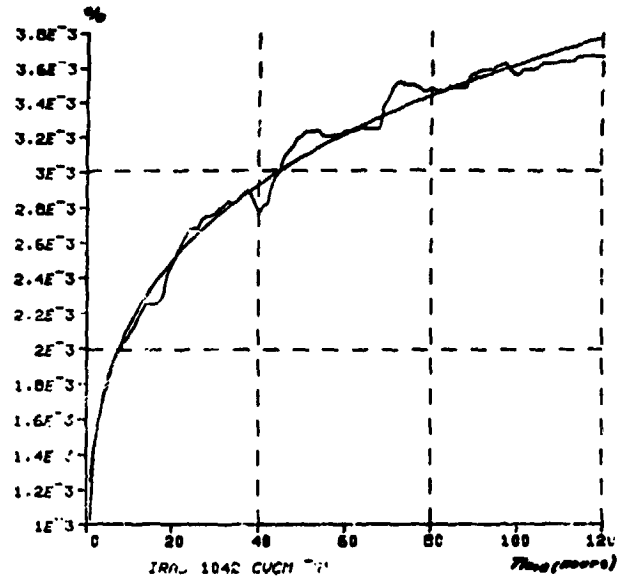
The zero value of the QCMs has been taken at the lowest value of signal observed after cooling of the QCMs and heating of sample, but this can be slightly overestimated because some contamination may already have occurred during the cooling.



3a

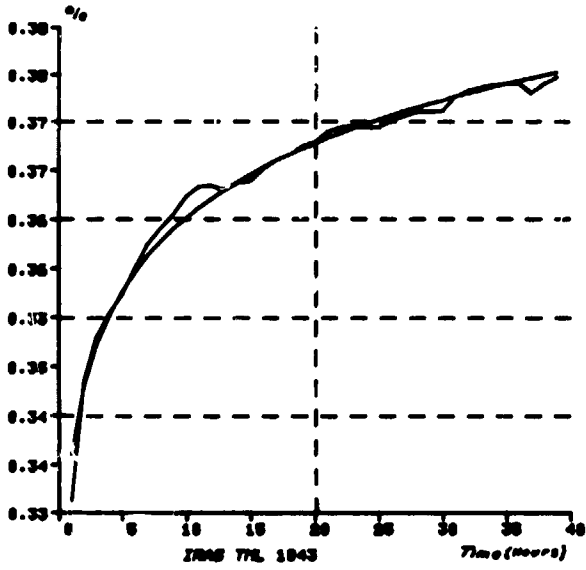


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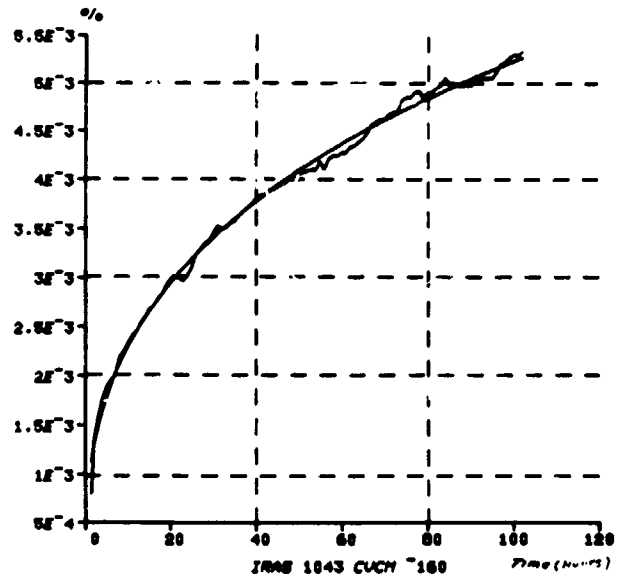


3c

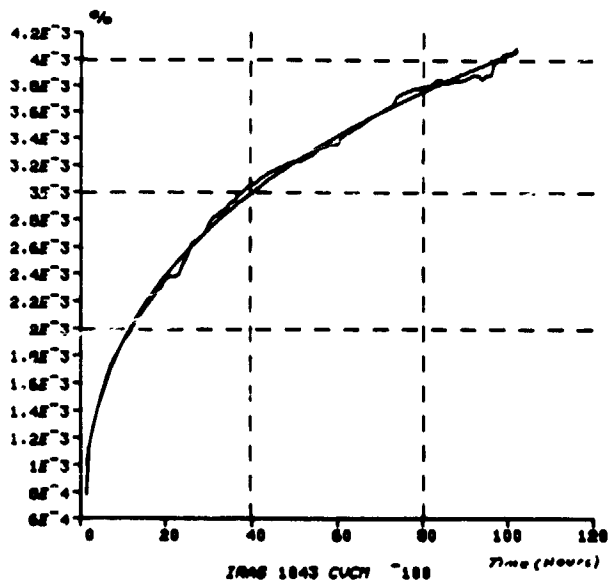
Figure 3



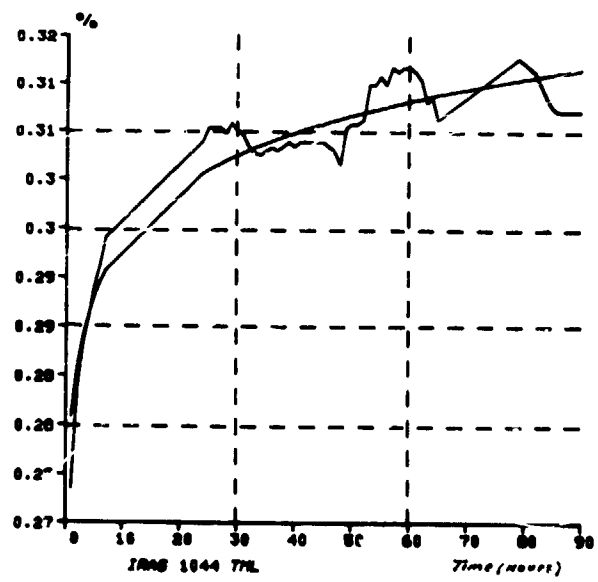
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3e

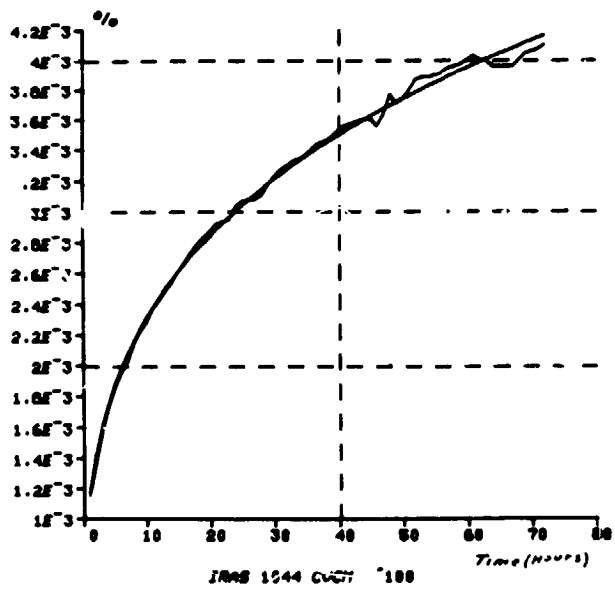


3f

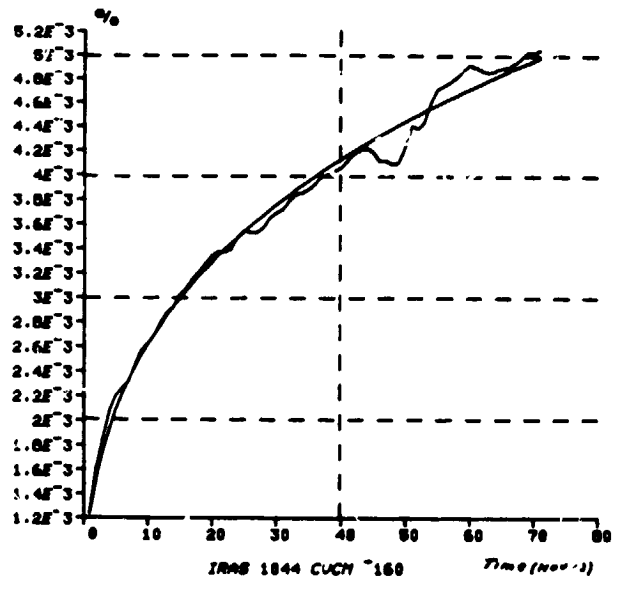


3g

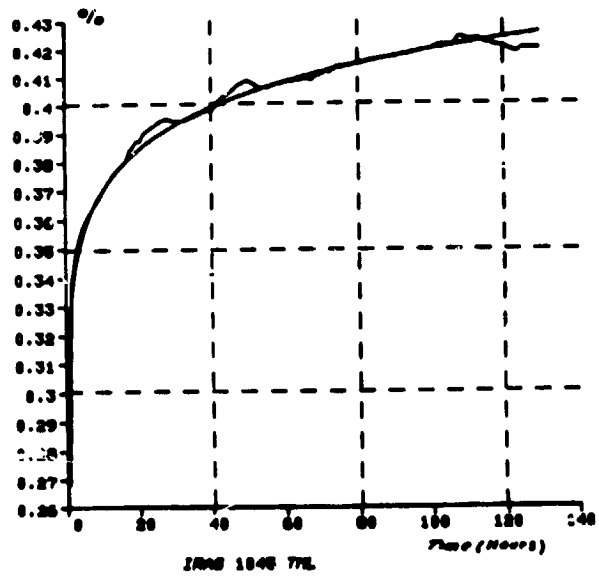
Figure 3



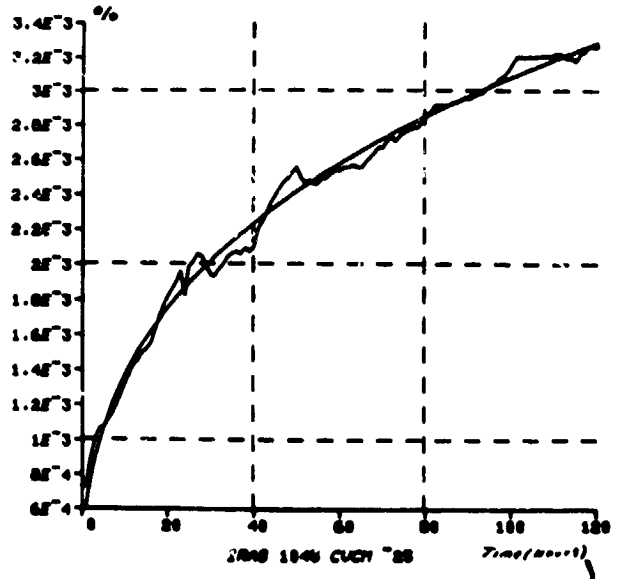
3h



3i

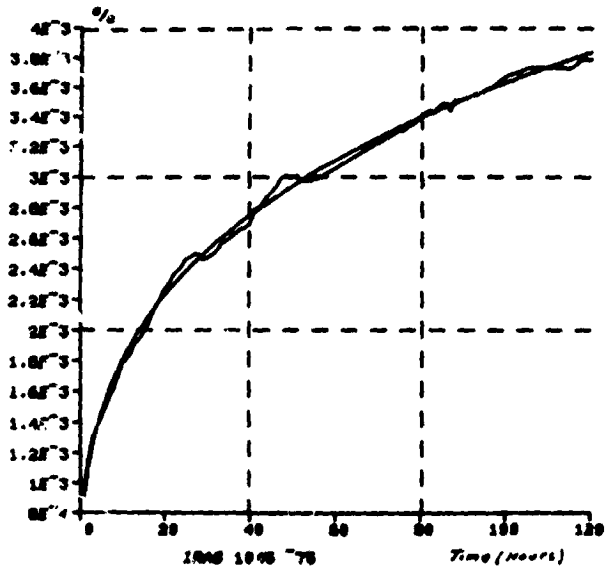


3j

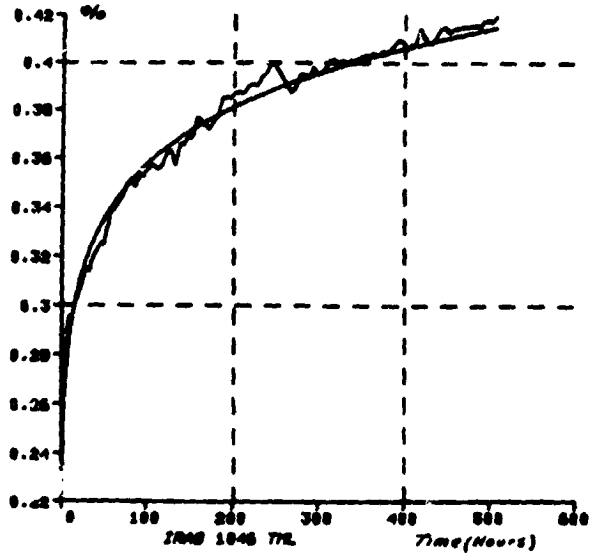


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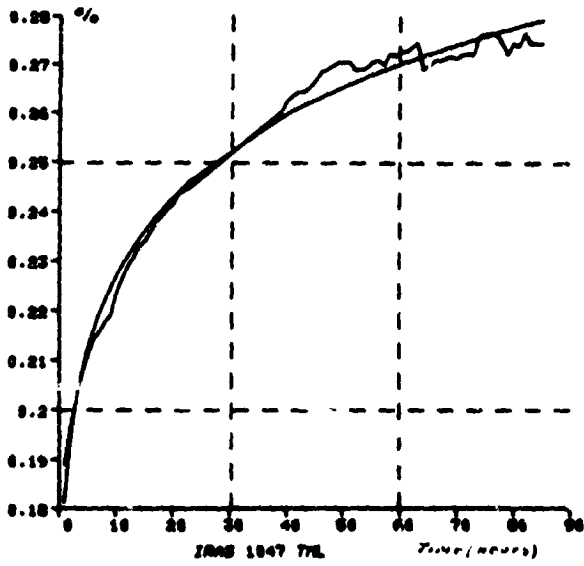
Figure 3



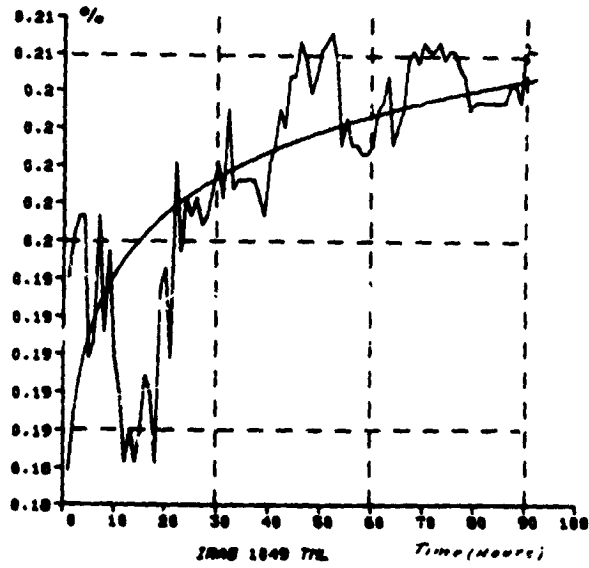
31



3m



3n



3o

Figure 3

7. COMPUTER CALCULATION METHOD

The method used is linear regression by equal increments. It is based on several tests of changes of variable, leading to a linear relation between the new variables and the necessary parameters by least square fit.

The calculation program is written in AFL. It consists of a series of sub-programs corresponding to different equations, which are tested successively by comparison with experimental data, particularly the power function $Y = aT^b$ and the exponent function $y = ae^{-bt}$.

Both equations are given; the correlation with the power function gives normally a better fit with experiment for durations not longer than 120 h.

This is the case for the IRAS tests.

7.1 The results are given as computer listing (see example of TML listing below)

```

-----
Y = 0.2344200336 = Y (0.09162737663E (-))
-----
1970 / ANS 6 / MOIS 11 / JOURS 14 / HEURES 13 /
REF 1 10750.1
POIDS 1 10750.1
-----

```

TIME(H)	MES-	CALC.	ERR-%%	RATE
1.0	2.6511E-1	2.3443E-1	11.874	2.1400E-2
2.0	2.7349E-1	2.4900E-1	8.6605	1.1144E-2
3.0	2.7967E-1	2.5926E-1	7.8992	7.9103E-3
4.0	2.8479E-1	2.6610E-1	5.0726	6.8974E-3
5.0	2.8891E-1	2.7160E-1	5.1761	4.9706E-3
6.0	2.8995E-1	2.7626E-1	4.7233	4.2108E-3
7.0	2.9209E-1	2.8019E-1	4.0750	3.6679E-3
8.0	2.9395E-1	2.8363E-1	3.5096	3.2472E-3
9.0	2.9405E-1	2.8671E-1	2.7703	2.9190E-3
10.0	2.9601E-1	2.8949E-1	2.1350	2.6620E-3
11.0	2.9501E-1	2.9437E-1	1.2774	2.4326E-3
12.0	2.9501E-1	2.9854E-1	0.4072	2.2477E-3
13.0	2.9674E-1	2.9654E-1	0.6609	2.0201E-3
14.0	2.9669E-1	2.9056E-1	0.8149	1.8540E-3
15.0	3.0000E-1	3.0043E-1	0.1512	1.6333E-3
16.0	3.0093E-1	3.0223E-1	0.4337	1.7380E-3
17.0	3.0232E-1	3.0392E-1	0.5271	1.6301E-3
18.0	3.0320E-1	3.0531E-1	0.7478	1.8532E-3
19.0	3.0410E-1	3.0703E-1	0.9307	1.4086E-3
20.0	3.0500E-1	3.0040E-1	0.9401	1.4132E-3
21.0	3.0604E-1	3.0906E-1	1.2163	1.3520E-3
22.0	3.0697E-1	3.1110E-1	1.3707	1.2250E-3
23.0	3.0790E-1	3.1245E-1	1.4769	1.2447E-3
24.0	3.0803E-1	3.1367E-1	1.5668	1.1973E-3
25.0	3.1063E-1	3.1409E-1	1.336	1.1839E-3
26.0	3.1163E-1	3.1590E-1	1.3973	1.1136E-3
27.0	3.1349E-1	3.1708E-1	1.1453	1.0766E-3
28.0	3.1442E-1	3.1813E-1	1.1087	1.0411E-3
29.0	3.1516E-1	3.1916E-1	1.2668	1.0004E-3
30.0	3.1442E-1	3.2018E-1	1.8243	0.7702E-4
31.0	3.1442E-1	3.2118E-1	2.1307	0.4913E-4

These listings give:

- a. the power function from which the results were calculated.
- b. the results:
 1. in column 1: time in hours
 2. in column 2: measured data (%)
 3. in column 3: data calculated from the equation (%)
 4. in column 4: difference between data calculated and measured
 5. in column 5: the rate in %/h

- 7.2 The different equations calculated for six tests are given in Tables 5 and 6.

We can see from these tables the differences which occur between equations corresponding to tests carried out at the same temperature. These differences and in some cases the absence of equation are due to technical incidents during tests (i.e. failure of oven, liquid nitrogen tank empty, high noise on the QCMs or failure of LN₂ regulation (LN₂ valves still open).

These incidents are the cause of variations in the data recorded (re-evaporation of contaminants from QCMs when the LN₂ is missing for example) and consequently of modification in the calculated equations. These incidents have been particularly frequent during the last three tests.

- 7.3 The curves measured and calculated (Figure 3) for TML and CVCM for each test indicate a fair correlation for the total mass loss, except for test 1049 (instabilities due to ice-drift on the vacuum balance), but are not conclusive in the case of CVCM.

8. PREDICTIONS

From the equations given in Tables 5 and 6, we calculated the % TML, % TML rate, % CVCM and % CVCM rate predictions from 1 to 10⁵ hours. These predictions are shown in Tables 7, 8 and 9.

9. CONCLUSION

The results obtained show large discrepancies between them. These are mainly due to technical incidents during the tests and inaccurate zero during the analysis of recordings.

These differences influenced the equations used to carry out the calculations for the predictions.

Concerning the form of equation used to carry out the calculation, the power function is the best one that could be found at the moment to fit the experimental data, but it is not in agreement with any theory that this casts a doubt on the far away extrapolation. To validate a theory, a lot of long time duration tests (minimum three hundred hours for each sample without incident) should have been run. The predicted outgassing after 10⁵ hours is, however, within a factor around 2 for TML and 10 for CVCM.

Notwithstanding their lack of accuracy, the results given in this paper should be sufficient to assess the contamination risk of the satellite with a reasonable confidence.

Action/failure	1042 time (h)	1043 time (h)	1044 time (h)	1045 time (h)	1046 time (h)	1047 time (h)	1049 time (h)
Mounting sample	-6	-27	-18	-5	-1	-1	-1
Pump down	-5	-26	-17	-4	0	0	0
Cooling QCMs	-3	-24	-15	-2			
Heating sample	0	0	0	0			
LN ₂ failure					47% to 105 tank empty		
Oven failure					302 and 304 h 390 and 395 h		
Noise effects (unknown origin, probably electrical)					No data on QCMs. Too much noise	No data on QCMs. Too much noise	No data on QCMs. Too much noise
LN ₂ valves frozen					Valves frozen	Valves frozen	Valves frozen

TABLE 1

0 : starting point of data

Test Number	Sample Number	TML T ^o C sample + 125 ^o C	CVCM -25 ^o C	CVCM -75 ^o C	CVCM -100 ^o C	CVCM -160 ^o C	Observations
1042	3	* X * 3h	* X * 3h	* X * 3h			* cooling time duration of QCMs before sample heating ** long dura- tic test (400 h) *** two tests have been carried out, 1st: 24h at 100 ^o C 2nd: one week at 125 ^o C after recovering at 65% RH, 25 ^o C during more than 48 h.
1043	1	X			* X * 24h	* X * 24h	
1044	2				* X * 15h	* X * 15h	
1045	4	X	* X * 2h	* X * 2h			
1046	**6	X T sample + 80 ^o C	X	X		X	
1047	***5	X T sample + 100 ^o C	X	X		X	
1049	5	X T sample + 125 ^o C	X	X		X	

TABLE 2

For the tests 1046 and 1047 the cooling of the QCM and heating of the sample have been started together under dry nitrogen at atmospheric pressure before pump down.

m/e	P=5x10 ⁻⁷ torr T2 (To+1) Amp	P=2x10 ⁻⁷ torr T2 (To+15) Amp	P=1.3x10 ⁻⁷ torr T3 (To+25) Amp	P=1.5x10 ⁻⁷ torr T4 (To+38) Amp	P=9x10 ⁻⁸ torr T5 (To+49) Amp	P=3x10 ⁻⁸ torr T6 (To+73) Amp	P=7x10 ⁻⁸ torr T7 (To+87) Amp
1	6 x10 ⁻¹¹	-	-	-	-	-	-
2	9.6x10 ⁻¹¹	3.2x10 ⁻¹²	2.9x10 ⁻¹²	1.7x10 ⁻¹²	1.9x10 ⁻¹²	1.4x10 ⁻¹²	2 x10 ⁻¹³
12	1.5x10 ⁻¹¹	2.5x10 ⁻¹³	-	-	-	-	-
13	-	-	-	-	-	-	-
14	6 x10 ⁻¹¹	2.3x10 ⁻¹²	2 x10 ⁻¹²	1.4x10 ⁻¹²	1.5x10 ⁻¹²	1.3x10 ⁻¹²	2 x10 ⁻¹³
15	1.5x10 ⁻¹¹	-	-	-	-	-	-
16	9 x10 ⁻¹¹	2.7x10 ⁻¹²	2 x10 ⁻¹²	1.7x10 ⁻¹²	1.5x10 ⁻¹²	1.1x10 ⁻¹²	5 x10 ⁻¹³
17	3 x10 ⁻¹⁰	7 x10 ⁻¹¹	6.2x10 ⁻¹²	4.2x10 ⁻¹²	3.5x10 ⁻¹²	2.8x10 ⁻¹²	1.3x10 ⁻¹²
18	1.3x10 ⁻⁹	2.2x10 ⁻¹⁰	1.4x10 ⁻¹⁰	1.1x10 ⁻¹⁰	8 x10 ⁻¹¹	8 x10 ⁻¹¹	4.9x10 ⁻¹²
28	6.9x10 ⁻¹⁰	3.4x10 ⁻¹⁰	2.9x10 ⁻¹⁰	2.3x10 ⁻¹⁰	2.6x10 ⁻¹⁰	1.7x10 ⁻¹⁰	1.6x10 ⁻¹⁰
32	1.2x10 ⁻¹⁰	6 x10 ⁻¹¹	8.9x10 ⁻¹²	6.6x10 ⁻¹²	8 x10 ⁻¹²	4 x10 ⁻¹²	3.5x10 ⁻¹²
40	2.1x10 ⁻¹¹	2.5x10 ⁻¹²	2.1x10 ⁻¹²	1.9x10 ⁻¹²	1.7x10 ⁻¹²	1.1x10 ⁻¹²	6.8x10 ⁻¹³
44	1.5x10 ⁻¹⁰	6 x10 ⁻¹¹	4.2x10 ⁻¹²	3 x10 ⁻¹²	2.2x10 ⁻¹²	1.3x10 ⁻¹²	9 x10 ⁻¹³
55	4 x10 ⁻¹²	-	-	-	-	-	-
57	4 x10 ⁻¹²	-	-	-	-	-	-
57	3 x10 ⁻¹²	-	-	-	-	-	-
69	3 x10 ⁻¹²	-	-	-	-	-	-
79	4 x10 ⁻¹²	-	-	-	-	-	-

TABLE 3

Note: To is the time of measurement of the pressure after the 2nd hour after pump down of the sample.

P is the pressure at the time when the recording has been carried out

Test Number	Sample Number	Results
1042	3	HC : 5.4 x 10 ⁻⁵ E : $\frac{3.1 \times 10^{-5}}{8.5 \times 10^{-5}} \text{ g}$
1043	1	HC : 2.5 x 10 ⁻⁵ E : $\frac{1.5 \times 10^{-5}}{4 \times 10^{-5}} \text{ g}$
1044	2	HC : 8.5 x 10 ⁻⁵ E : $\frac{2.6 \times 10^{-5}}{1.11 \times 10^{-4}} \text{ g}$
1045	4	HC : 1.25 x 10 ⁻⁴ E : $\frac{0.70 \times 10^{-4}}{1.95 \times 10^{-4}} \text{ g}$
1046	6	HC : 2.04 x 10 ⁻⁵ E : $\frac{8.90 \times 10^{-6}}{2.93 \times 10^{-5}} \text{ g}$
1047	5	HC : 2.89 x 10 ⁻⁵ E : $\frac{1.13 \times 10^{-5}}{4.02 \times 10^{-5}} \text{ g}$

TABLE 4

HC = hydrocarbon
E = ester

These results have been obtained according to document PSS-15/QRM-05T.

Test No.	% TML	Sample Temp.	Rate TML (%/h)
1042	0.03660 0.2980(T)	125°C	1.4567x10 ⁻² T ^{-0.96340}
1043	0.02976 0.3409(T)	125°C	1.0145x10 ⁻² T ^{-0.97024}
1044	0.02662 0.280(T)	125°C	7.4772x10 ⁻³ T ^{-0.97338}
1045	0.5523 0.3355(T)	125°C	1.0529x10 ⁻² T ^{-0.94477}
1046	0.09162 0.2344(T)	80°C	2.1475x10 ⁻² T ^{-0.90938}
1047	0.09742 0.1812(T)	100°C	1.7648x10 ⁻² T ^{-0.90260}
1049	0.02330 0.1873(T)	125°C	4.375 x10 ⁻² T ^{-0.97670}

TABLE 5

Test Number	% CVCM	Temp. °C	Rate CVCM (%/h)
1042	0.001107T 0.1916	-25	2.1210x10 ⁻⁴ T -0.6084
1042	0.001246T 0.2311	-75	2.8795x10 ⁻⁴ T -0.7689
1043	0.000904T 0.3256	-100	2.9317x10 ⁻⁴ T -0.6744
1043	0.001012T 0.3570	-160	4.0286x10 ⁻⁴ T -0.6430
1044	0.001161T 0.2987	-100	3.4679x10 ⁻⁴ T -0.7013
1044	0.001232T 0.3276	-160	4.0360x10 ⁻⁴ T -0.6724
1045	0.000611T 0.3513	-25	2.1464x10 ⁻⁴ T -0.6487
1045	0.000899T 0.3026	-75	2.7203x10 ⁻⁴ T -0.6974
1046	ND	-75	ND
1046	ND	-75	ND
1047	ND	-25	ND
1047	ND	-25	ND
1049	ND		ND
1049	ND		ND

TABLE 6

Time	test 1042	test 1043	test 1044	test 1045	test 1046	test 1047	test 1049
1	2.98x10 ⁻¹	3.45x10 ⁻¹	2.80x10 ⁻¹	2.96x10 ⁻¹	2.34x10 ⁻¹	1.81x10 ⁻¹	1.88x10 ⁻¹
10	3.24x10 ⁻¹	3.65x10 ⁻¹	2.98x10 ⁻¹	3.81x10 ⁻¹	2.89x10 ⁻¹	2.26x10 ⁻¹	1.98x10 ⁻¹
10 ²	3.52x10 ⁻¹	3.91x10 ⁻¹	3.17x10 ⁻¹	4.32x10 ⁻¹	3.57x10 ⁻¹	2.83x10 ⁻¹	2.09x10 ⁻¹
10 ³	3.83x10 ⁻¹	4.18x10 ⁻¹	3.37x10 ⁻¹	4.91x10 ⁻¹	4.13x10 ⁻¹	3.55x10 ⁻¹	2.21x10 ⁻¹
10 ⁴	4.17x10 ⁻¹	4.48x10 ⁻¹	3.58x10 ⁻¹	5.58x10 ⁻¹	5.45x10 ⁻¹	4.44x10 ⁻¹	2.33x10 ⁻¹
10 ⁵	4.54x10 ⁻¹	4.80x10 ⁻¹	3.81x10 ⁻¹	6.35x10 ⁻¹	6.73x10 ⁻¹	5.56x10 ⁻¹	2.46x10 ⁻¹

TABLE 7

Time	test 1042	test 1043	test 1044	test 1045	test 1046	test 1047	test 1049
1	1.456x10 ⁻²	1.014x10 ⁻²	7.472x10 ⁻³	1.853x10 ⁻²	2.147x10 ⁻²	1.764x10 ⁻²	4.375x10 ⁻³
10	1.585x10 ⁻³	1.086x10 ⁻³	7.944x10 ⁻⁴	2.103x10 ⁻³	2.651x10 ⁻³	2.208x10 ⁻³	4.016x10 ⁻⁴
10 ²	1.724x10 ⁻⁴	1.163x10 ⁻⁴	8.44x10 ⁻⁵	2.38x10 ⁻⁴	3.273x10 ⁻⁴	2.764x10 ⁻⁴	4.871x10 ⁻⁵
10 ³	1.875x10 ⁻⁵	1.246x10 ⁻⁵	9.981x10 ⁻⁶	2.712x10 ⁻⁵	4.042x10 ⁻⁵	3.459x10 ⁻⁵	5.140x10 ⁻⁶
10 ⁴	2.041x10 ⁻⁶	1.334x10 ⁻⁶	9.53x10 ⁻⁷	3.080x10 ⁻⁶	4.992x10 ⁻⁶	4.329x10 ⁻⁶	9.14x10 ⁻⁷
10 ⁵	2.22x10 ⁻⁷	1.43x10 ⁻⁷	1.02x10 ⁻⁸	3.50x10 ⁻⁷	6.16x10 ⁻⁷	5.42x10 ⁻⁷	5.7x10 ⁻⁸

TABLE 8

*** see test conditions

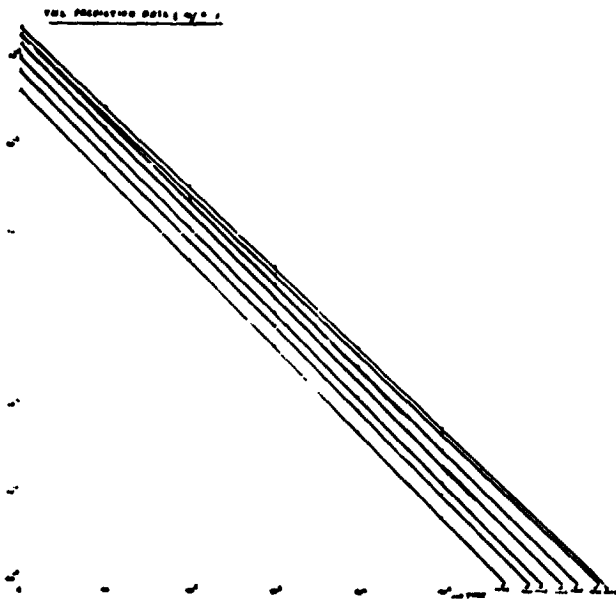
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Time (hrs)	test 1042 at -25°C % CVCM	test 1042 at -25°C %/h	test 1042 at -75°C % CVCM	test 1042 at -75°C %/h	test 1043 at -100°C % CVCM	test 1043 at -100°C %/h	test 1043 at -160°C % CVCM	test 1043 at -160°C %/h
1	1.11×10^{-3}	2.12×10^{-4}	1.25×10^{-3}	2.87×10^{-4}	9.00×10^{-4}	2.93×10^{-4}	1.01×10^{-3}	4.02×10^{-4}
10	1.72×10^{-3}	3.29×10^{-5}	2.12×10^{-3}	4.9×10^{-5}	1.9×10^{-3}	6.2×10^{-5}	2.30×10^{-3}	9.16×10^{-5}
10^2	2.67×10^{-3}	5.12×10^{-6}	3.61×10^{-3}	8.34×10^{-6}	4.03×10^{-3}	1.3×10^{-5}	5.23×10^{-3}	2.08×10^{-5}
10^3	4.16×10^{-3}	7.96×10^{-7}	6.14×10^{-3}	1.42×10^{-6}	8.53×10^{-3}	2.77×10^{-6}	1.19×10^{-2}	4.74×10^{-6}
10^4	6.46×10^{-3}	1.23×10^{-7}	1.05×10^{-2}	2.41×10^{-7}	1.80×10^{-2}	5.19×10^{-7}	2.71×10^{-2}	1.08×10^{-6}
10^5	1×10^{-2}	1.92×10^{-8}	1.78×10^{-2}	4.11×10^{-8}	3.82×10^{-2}	1.24×10^{-7}	6.16×10^{-2}	2.45×10^{-7}

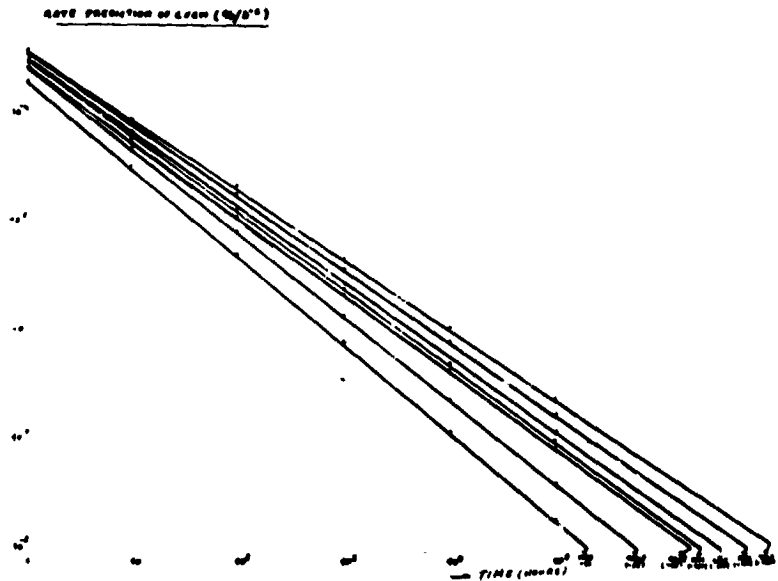
Time (hrs)	test 1044 at -100°C % CVCM	test 1044 at -100°C %/h	test 1044 at -160°C % CVCM	test 1044 at -160°C %/h	test 1045 at -25°C % CVCM	test 1045 at -25°C %/h	test 1045 at -75°C % CVCM	test 1045 at -75°C %/h
1	1.16×10^{-3}	3.46×10^{-4}	1.23×10^{-3}	4.03×10^{-4}	6.11×10^{-4}	2.15×10^{-4}	9×10^{-4}	2.72×10^{-4}
10	2.31×10^{-3}	6.9×10^{-5}	2.62×10^{-3}	8.58×10^{-5}	1.37×10^{-3}	4.81×10^{-5}	1.6×10^{-3}	1.1×10^{-5}
10^2	4.6×10^{-3}	1.37×10^{-5}	5.57×10^{-3}	1.82×10^{-5}	3.08×10^{-3}	1.08×10^{-3}	3.62×10^{-3}	1.1×10^{-5}
10^3	9.13×10^{-3}	2.73×10^{-6}	1.18×10^{-2}	3.82×10^{-6}	6.9×10^{-3}	2.43×10^{-6}	7.27×10^{-3}	2.2×10^{-6}
10^4	1.91×10^{-2}	5.43×10^{-7}	2.51×10^{-2}	8.24×10^{-7}	1.55×10^{-2}	5.45×10^{-7}	1.46×10^{-2}	4.41×10^{-7}
10^5	3.61×10^{-2}	1.08×10^{-7}	5.35×10^{-2}	1.75×10^{-7}	3.48×10^{-2}	1.22×10^{-7}	2.93×10^{-2}	8.86×10^{-8}

TABLE 9

These results are plotted on the following curves.



TML prediction rates



CVCM prediction rates