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STS-1 MISSION CONTAMINATION EVALUATION APPROACH

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ABSTRACT

The Space Transportation System 1 mission will be the first opportunity to assess the induced environment of the Orbiter payload bay region. Two tools have been developed to aid in this assessment. The Shuttle Payload Contamination Evaluation computer program has been developed to provide an analytical tool for prediction of the induced molecular contamination environment of the Space Shuttle Orbiter during its onorbit operations. An Induced Environment Contamination Monitor has been constructed and tested to measure the Space Shuttle Orbiter contamination environment inside the payload bay during ascent and descent and inside and outside the payload bay during the onorbit phase. Measurements will be performed during the four Orbital Flight Test series. Measurements planned for the first flight have been described and predicted environmental data have been discussed in detail. The results indicate that the expected data are within the measurement range of the Induced Environment Contamination Monitor instruments evaluated for this paper, and therefore it is expected that useful contamination environmental data will be available after the first flight.

INTRODUCTION

Several aspects of the upcoming Space Transportation System 1 (STS-1) mission, which will be the initial launch, onorbit, and entry exposure of the Space Shuttle Orbiter to the space environment, are important to consider from a payload exposure standpoint. The Space Shuttle system was developed with the objective of providing a minimal contamination environment together with a versatile Earth-orbital payload delivery system and experimentation base. Many payloads already determined and many being considered for Shuttle-based operations are very sensitive to spacecraft-induced environmental contaminants. In addition, the multiple-reuse capability of the Space Shuttle necessitates unique considerations for payloads.

The induced environment of the Orbiter payload bay will be assessed for the STS-1 mission. Specific plans developed for the STS-1 mission are based on a multiphase approach philosophy that consists of (1) development of the contamination math model, (2) development of the contamination measurement instrumentation, (3) prediction of contamination, (4) measurement of contamination, (5) correlation of predictions and measurements, (6) update of the modeling process, and (7) application of the updated model to predict the induced contamination environment of future missions.

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This paper describes the contamination math model used in making preflight predictions and discusses predictions made for STS-1, describes the instrumentation that will be used in performing contamination measurements, and outlines the method for correlating predictions and measurements to assess overall mission contamination.

CONTAMINATION MODEL

Model Background

The Shuttle Payload Contamination Evaluation (SPACE) computer program was developed to provide an analytical tool with which to predict the external induced molecular contaminant environment of the Space Shuttle Orbiter during onorbit operations. It has been developed over a period of several years at Martin Marietta Aerospace, Denver Division, under contract to the NASA Lyndon B. Johnson Space Center (JSC). The SPACE program mathematically synthesizes the induced environment for the six major contaminant sources: (1) nonmetallic materials outgassing (i.e., the long-term bulk mass loss of material upon exposure to space vacuum), (2) early desorption from external surfaces (i.e., the initial high mass loss of absorbed and adsorbed volatiles, gases and liquids), (3) cabin atmosphere leakage from pressurized crew compartments, (4) two supplemental flash evaporator vent effluents, (5) thirty-eight 3.9-kilonewton (870-pound) reaction control system (RCS) thrusters, and (6) six 0.1-kilonewton (25-pound) vernier control system (VCS) thrusters. Other sources can be easily added to the model.[1,2] The SPACE program predicts surface deposition and return flux (RF) on surfaces with up to 2π-steradian field-of-view molecular densities, and molecular number column densities (NCD) (which is the integrated density along a line of sight to infinity) for 17 lines of sight. Included in the model are a definition of Orbiter geometry (approximately 300 nodes); viewfactors between modeled surfaces and points along the 17 lines of sight; Orbiter source characteristics such as mass loss/emission rates, time and temperature dependence, and sticking coefficient; and effects such as surface reflection/re-emission, return flux/ambient scattering, return flux/self-scattering and surface deposition.

Updating and Modeling for STS-1

The SPACE program has been updated in several areas to increase its capability for contamination assessment of STS-1. The first of these changes has encompassed surface contamination exchange in the payload bay; this update ultimately has taken the form of an "unlimited surface" multireflection capability with an approximate step solution. The model has also been updated to increase data handling and presentation; this update includes additions to the number of lines of sight from 17 to 25 in the far field as well as modification of the point matrix to include 50 lines of sight with 1.0 meter resolution in the near vicinity (<16 meters) of the Shuttle Orbiter. A special program has also been incorporated into SPACE to provide a variety of plotting capabilities.

In addition, the SPACE computer program has encompassed the modeling of the STS-1 configuration in the Orbiter payload bay, including the Induced Environment Contamination Monitor (IECM), the instrument package used to measure the contamination environment. Figure 1 shows the geometric modeling of the STS-1 payload configuration. This configuration is made up of the three development flight instrumentation (DFI) packages and the IECM package, which includes the quartz crystal microbalances (QCM's) and the mass spectrometer (MS) to be used for the STS-1 mission analysis. These instruments and others on the IECM will be discussed in more detail.

CONTAMINATION MEASUREMENT INSTRUMENTS

IECM System and Instruments

In this section, the IECM system and instruments are reviewed in outline form and the associated STS-1 operations are discussed. The IECM (fig. 2) is a self-contained (with the exception of Orbiter power and one astronaut-operated switch) minimum-interface payload. The instrument weighs 360 kilograms and is 124 centimeters long, 190 centimeters wide, and 79 centimeters high, corresponding to Orbiter X, Y, and Z axes, respectively. The extruded aluminum framework houses 10 STS-1 instruments, the data system, the tape recorder, the power distributor, the voltage regulator, and the batteries.

Thermal control of the IECM will be accomplished through a combination of passive and active means. The surfaces of the IECM will be passively cooled through radiation exchange from the 3/8-inch-thick aluminum baseplate and the aluminum side and bottom baffles. External panels are coated with S-13g LO. Ten 28-V dc electrical heaters are used to maintain thermal control during the cold case. Table I gives the physical and performance characteristics of the IECM instruments. In addition to standard instrument calibration, a special calibration using typical STS materials is being performed for the mass spectrometer at the University of Michigan, Space Physics Research Laboratories. The response of the IECM mass spectrometer to the outgassing of these materials will be compared to that of a laboratory mass spectrometer.

Each instrument and component was qualified and tested under vacuum conditions, individually and again with the system in the final configuration. The major system qualification tests consisted of temperature cycling, vibration, electromagnetic interference, thermal vacuum, and outgassing. Worst-case thermal vacuum testing was performed during September 1979 to confirm the thermal design. Included in these tests were hot-case onorbit, cold-case onorbit, and hot-case descent and postlanding. The IECM performed well during these tests after initial minor problems were corrected, without exceeding design temperature limits on critical components (i.e., batteries, data acquisition and control system, voltage regulator, and power distributor) or on the scientific instruments.

IECM Operations

The IECM was designed to monitor payload-bay contamination at its location in the cargo bay during all phases of the STS-1 mission, including ground operations. The IECM will be operational before the STS-1 mission in the Orbiter Processing Facility (OPF) after final "cleanup" of the payload bay and before payload bay door closure. At least two sets of measurements will be made on the launch pad to obtain the integrated environmental effects of the Orbiter transfer from the OPF to the Vertical Assembly Building (VAB) and to the launch pad as well as to obtain environmental data on the pad facility itself. Other useful data will be taken by the IECM during this time frame coincidental with other checkouts and tests.

Ascent measurements begin with the IECM launch mode signal, which turns on the cascade impactor, the dewpoint hygrometer, the humidity monitor and the air sampler. Ascent measurements end with the onorbit signal to the IECM, at which time the onorbit-phase measurements begin. For the STS-1 mission, the mass spectrometer will scan from 1 to 150 amu (atomic mass units) in 300 seconds and then remain for an equal time period (300 seconds) on the water peak (18 amu). This operational mode was selected because of the importance of water as a potential contaminant. This cycle is repeated for the duration of the onorbit phase (more than 200 spectra). See figure 3.

The onorbit signal also begins the preprogramed temperature-controlled quartz crystal microbalance (TQCM) temperature cycling routine designed to obtain information on mass condensation at temperatures of 303, 273, 243, and 213 K (30°, 0°, -30°, and -60° C) for 90 minutes at each temperature with a 353 K (80° C) 30-minute cleanup cycle between each successive setting. At the end of the 213 K (-60° C) setting, the TQCM's are driven to 243, 273, and 303 K (-30°, 0°, and 30° C) at 30-minute intervals to measure discrete evaporation of condensed materials. The cycle is then repeated throughout the mission. Figure 4 shows one cycle of the TQCM temperature sequence.

In preparation for descent before payload bay door closure, the astronaut actuates the mass spectrometer switch, which turns the instrument off and mechanically seals the unit against repressurization. Upon receipt of the deorbit command, the IECM turns off the camera photometers and turns on the cascade impactor, dewpoint hygrometer, humidity monitor, and air sampler. The air pumps for the latter instruments are turned on at about an 18-kilometer altitude by timing from the deorbit signal.

This paper has, by design, been limited to discussing primarily the mass spectrometer and the QCM's. The other instrumentation is discussed in more detail in references 3 and 4. In addition, the IECM instruments previously mentioned and the operation of the IECM after landing are discussed. (The IECM continues to operate in the descent mode for about 1 hour after landing to obtain data on the postlanding environment.) Reference 4 also contains a discussion of the IECM systems and thermal design.

References 5 and 6 concern the TQCM, the cryogenic quartz crystal microbalance (CQCM), and the mass spectrometer, giving greater detail about these instruments for which the onorbit modeling validation will heavily depend.

CONTAMINATION ASSESSMENT

The SPACE math model (the contamination predictive tool) and the IECM instrumentation (the contamination measurement tool) have been described. In this section, the use of these primary tools to assess the STS-1 contamination levels will be discussed.

STS-1 Mission Conditions

There are various STS-1 parameters and assumptions that have been made for premission contamination predictions. The first series of these can be classified as operational flight requirements[7] and include

1. A 280-kilometer (150-nautical-mile) circular-orbit altitude

2. A launch inclination of between 32° and 42°

3. A 54-hour flight duration

4. A beta (Sun) angle not to exceed 60°

5. Payload bay to earth, which is referred to as Z local vertical (ZLV) and the main (X) axis perpendicular to the orbital plane (POP) except as required for operational or test activities

The STS-1 operational requirements lead to the establishment of certain conditions that have a significant influence on the amount of contamination detected by the IECM instruments.

1. The ambient atmospheric density is assumed to be the "medium" density at a 280-kilometer (150-nautical-mile) altitude. The return flux is due to collisions between induced contamination molecules and ambient environment molecules and is density dependent.

2. During the relatively long periods of ZLV attitude, the Orbiter thermal protection system (TPS) temperatures tend to level out, avoiding temperature extremes. As a result, outgassing rates for exterior surfaces are nominal. Also, Orbiter surfaces do not reach temperatures low enough for H_2O condensation (ice buildup) for any significant period of time; therefore, H_2O is readily reflected.

3. The ambient molecule velocity vector (V) is perpendicular to the Orbiter Z-axis during periods of Orbiter ZLV attitude. This case is of

special interest due to its relatively long duration during the flight. The case of maximum return flux (V parallel to Orbiter Z-axis) is evaluated for comparison (worst case).

In addition, there are other parameters that influence the measurement and prediction of contamination levels. For example, IECM instrument operation, performance, and output depend significantly on the position of (1) payload bay doors and payload bay vent doors and (2) Orbiter elevon.

Open payload bay door conditions permit unrestricted onorbit instrument operation. However, when the payload bay doors are closed even for a short period of time, the gas pressure within the bay can rise to an unacceptable level at which the IECM mass spectrometer characteristics are changed and, possibly, to the point at which the mass spectrometer is damaged. Even though the vent doors will remain open, the mass spectrometer is not scheduled to be operational until after the early door closings. The payload bay doors are open during the remainder of the onorbit period except for the "deorbit rehearsal" period (fig. 3), when they will be closed preparatory to potential re-entry. Since the vent doors will be closed during this period, the mass spectrometer will be turned off to prevent damage. The other IECM instruments will continue to operate in nominal or orbit mode during this time.

The elevon, as a portion of the wing, contributes to the reflection of molecules from the RCS/VCS engines and the flash evaporator plume. For purposes of analytical prediction of the contamination environment for this flight, the elevon is assumed to be in the nominal position (0° angle).

To complete the definition of the parameters necessary for contamination predictions, the specific Orbiter sources and contamination measurement instrumentation sensors valid for the STS-1 mission are discussed briefly.

Table 3 lists the species, the effluent rate, the duration, and the approximate time line for the major Orbiter contaminant sources of early desorption, outgassing, cabin atmosphere leakage, the 3.9-kilonewton (870-pound) RCS engines, the 1-kilonewton (25-pound) VCS engines, the Orbiter maneuvering system (OMS) engines, and the primary water sources (the flash evaporator vents, the potable (supply) water dump, and the waste water dump).

The contamination measurement capability on the STS-1 consists of the IECM mounted in the payload bay, as previously mentioned. The instruments on the "top" surface of the IECM (fig. 2) are pointing in the Orbiter +Z direction, which will be called line of sight one (LOS1). Depending on the field of view, these instruments (except for the two camera photometers) receive little or no direct contamination from the Orbiter and, because of their location, are only exposed to what is referred to as return flux. This flux results from collisions with other contamination molecules/particles (self-scattering) or collisions with ambient molecules (ambient scattering). The mass spectrometer, with its limited field of view (10° optimum), is operated at "low" bit rate and, as a result, cycles through its mass range in about 10 minutes. The TQCM temperature varies according to a 10-hour cycle (fig. 4). Therefore, the mass spectrometer as well as the TQCM are sensitive to a particular contaminant species only at certain limited time periods during the mission. These times may not necessarily coincide with the brief contamination dumps.

The CQCM temperature depends on the Orbiter attitudes. Calculated cool-down temperatures for the CQCM show that about 10 to 15 hours are required in deep-space orientation to reach temperatures capable of condensing water. The STS-1 attitudes (primarily ZLV and short deep-space orientations) will not allow the condensation of water.

The TQCM's mounted on the sides of the IECM will receive direct contamination flux from Orbiter surfaces, particularly payload bay surfaces. Predictions of expected deposition rates are not yet available.

Predictions of the Induced Molecular Contamination Environment

The three standard indicators of the induced molecular contamination environment are density, molecular number column density, and return flux, as discussed previously. The goal is to predict as well as to measure these variables. Prediction is accomplished by math modeling using the SPACE computer program. Measurements obtained during the STS-1 mission by various instruments of the IECM will be restricted mainly to the determination of return flux. In addition to the return flux values, predicted values for number column density are provided. Some major induced molecular contamination environment contributors noted for duration of activity or relative high rate, or both, and for probability of detection are crew cabin leakage, outgassing/desorption, and the flash evaporator. Predictions for these sources have been summarized (table 4). In table 4, NCD and RF are shown for the total number of molecules. The outgassing data are based on a rate obtained after a lengthy period of 48 hours or more. Rates measured early in the mission may be one to two decades higher. The MS (RF) output is derived from RF (LOS1) data for two specific Orbiter attitudes (ZLV (XPOP) and RAM condition). The ZLV is the primary stable attitude during this mission and RAM represents the case of maximum return flux (i.e., with the payload bay pointing in the flight direction).

When the MS output is discussed, the specific expected spectra output for outgassing is not known. Therefore, to calculate meaningful sensor outputs, the highest mass peak in the predicted spectrum is assumed to correspond to approximately 10 percent of the total output. Although this percentage is somewhat arbitrary, the derived sensor outputs fall within the instrument sensitivity range.

The TQCM (RF) outputs are derived from RF (LOS1) data. The average mass is assumed to equal 100 for outgassing and the condensation coefficient at a crystal temperature of 213 K (-60° C) is equal to one. The deposition rate decreases with increasing crystal temperature (decreasing condensation coefficient). The flash evaporator and cabin leakage do not contribute to the deposition rate because sticking coefficients for the species are zero for the entire TQCM temperature range. The values listed in table 4 are within the normal measurement range of those instruments; however, to accumulate enough contamination on the TQCM sensing crystal to be counted will take some time. Other sources, such as supply and waste water tanks, also contribute to the instrument output. These tanks are vented occasionally (table 3). The rates are high compared with the flash evaporator but are of relatively short duration. These H_2O dumps will be detected by the mass spectrometer, depending on the Orbiter attitude at the time of the dump since their duration exceeds the mass spectrometer cycle time.

A small fraction of the OMS, RCS, and VCS engine exhausts (namely, monomethyl hydrazine - nitrogen tetroxide) will accumulate on the TQCM during the mission. A few of the 80-millisecond bursts of gas species from engine firings may be measured by the mass spectrometer when spectral scan and exhaust time coincide. The same holds true for gases from sources such as the fuel cells and the auxiliary power unit.

These predictions (table 4) cover only part of the mission. It is expected that the instruments will show outputs during other portions of the mission, but lack of definition of the event time line and the randomness and short duration of the event preclude their prediction from a practical point of view. Therefore, a detailed evaluation of such events will be conducted postmission.

Inflight Monitoring

To obtain a time line of mission events not predicted premission and to take into account changes from premission to the actual time line, inflight monitoring is planned. The approach is as follows.

1. Significant Orbiter events are monitored real time during the mission to define the actual contamination event time line. This time line forms the basis for the assessment of IECM instrument output. These data are stored during flight on an onboard tape recorder. The parameters monitored define (a) the Orbiter characteristics and (b) the IECM status, as expressed by the IECM switch position (table 2), and the IECM power profile. The power profile provides indications of instrument operation cycles. Actual individual instrument output cannot be monitored.

2. IECM instrument outputs are surveyed to look for additional unexplained significant output characteristics. Attempts will then be made to correlate these outputs with any Orbiter-related events. All values of measured Orbiter parameters are recorded on tapes for later retrieval.

Postflight Data Reduction

Flight data concerning the contamination measurements will come from two different sources: the Orbiter and the IECM. Orbiter-related parameter data will be collected during the flight and reduced in detail after the flight at the NASA Marshall Space Flight Center (MSFC). Orbiter/IECM data analysis and assessment will be a joint JSC/MSFC effort, and the results will be published.

CONCLUDING REMARKS

An evaluation of the Orbiter-induced environment for the STS-1 mission has been performed. The evaluation approach consisted of developing a contamination model to predict the Orbiter-induced environment and developing an instrumentation package to measure the contamination environment. These tools will be applied for the first time on the STS-1 mission.

Based on this evaluation the following points can be made.

1. The STS-1 time line indicates that, for most of the mission, the Orbiter attitude varies frequently. Because the actual combination of attitude and source function for these periods is unknown, predictions of instrument output are impractical.

2. Two periods of the mission have stable (ZLV) attitudes and permit predictions of return flux for various Orbiter sources. For these attitudes, the predicted Orbiter-source return flux falls within the IECM instrument range and meaningful measured data are expected. For example, predictions of outgassing, flash evaporator output, and cabin leakage have been evaluated in detail.

3. For most periods of the mission, where attitude is variable, instruments of the IECM will continue to measure the contamination environment from Orbiter sources. Because no premission predictions will be available, these measured outputs will be correlated with the actual flight time line on a postmission basis.

4. Transient source events will, in some instances, be measured by several of the IECM instruments, depending on the instrument field of view and operating cycle. The evaluation of these data will also be performed postmission.

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TABLE I.- IECM INSTRUMENT CHARACTERISTICS AND MEASUREMENTS SUMMARY

Instrument (a)	Measurement	Operation (b)	Power Requirements, W	Field of view, deg	Sample rates	Resolution	Accuracy
Humidity monitor	Relative humidity, temperature	GPL, A, D, PL	4		6/min	±0.5%	±4%, typical ±2%, 273 to 343 K (0° to 70° C)
Dewpoint hydrometer	Dewpoint	GPL, A, D, PL	Normal: 5.5 Max. (transient) mode: 9		1/min	±0.5%	±1%, 266 to 300 K (-6.7° to 26.7° C)
Air sampler	Gaseous contaminants	GPL, A, D, PL	Operating mode: 28.6 Standby: 11.6			(d)	(d)
Cascade impactor	Particulate contamination of nonvolatile residue	GPL, A, O, D, PL	Operating mode: 10 Average standby: 3.0	[c]120	1/min GPL 6/min A, D, PL	$\pm 1.$[illegible] $\times 10^{-9}$ g	30×10^{-9} g
PSA	Optical degradation due to accumulated contamination	GPL, A, O, D, PL		150	(e)	(e)	(e)
OEM	Degradation of optics at 253.65 nm	GPL, O, D, PL	Operating mode: 41 Standby: 25	120	8 3 min/cycle	±0.8%	±1%
TQCM	Condensed molecular contamination at 213 to 303 K (-60° to +30° C)	GPL, A, O, D, PL	Operating mode: 73 (Max.) standby: 1.85	120	12/min/sensor A, D, PL 1/min/sensor GPL, O	$\pm 1.56 \times 10^{-9}$ g	1.5×10^{-8} g
CQCM	Condensed molecular contamination at 133 K (-140° C) to ambient	GPL, A, O, D, PL	Operating mode: 3.08 (Max.) standby: 1.33	120	12/min A, D, PL 1/min GPL, O	$\pm 1.65 \times 10^{-9}$ g	1.5×10^{-8} g
Camera/ photometer	Particulate velocity, direction; photometry	O	Operating mode: 47.6/ camera (Max.) standby: 14.0/ camera	20	Film: 150 sec/exp Chopper: 1/ sec Photometer: 1/sec	20-μm particle at 1 m/sec	±5 μm
Mass spectrometer	Molecular return flux	O	16	20	0.5/sec (slow scan) 5/sec (fast scan)	±1 count	0.2 to 0.4% for counting rate >512/sec

[a]PSA = passive sample array, OEM = optical effect module, TQCM = temperature-controlled quartz crystal microbalance, and CQCM = cryogenic quartz crystal microbalance.

[b]GPL = ground prelaunch, A = ascent, O = onorbit, D = descent, and PL = postlanding.

[c]Nonvolatile residue stage.

[d]See table III.

[e]Samples for lab analysis.

TABLE II.- IECM SWITCH POSITION SEQUENCE

Event	IECM switch position	Function
Launch configuration	2	Mass spectrometer off: valve 1 closed valve 2 open (case 1)
1 to 2 hr after payload bay door opening on revolutions 1 and 2	1	Mass spectrometer on: both valves open (case 2)
15 to 45 min before payload bay door closure on rehearsal day	2	Mass spectrometer off: valves remain open (case 2)
30 to 90 min after payload bay door opening on rehearsal day	1	Mass spectrometer on: valves remain open (case 2)
15 to 45 min before payload bay door closure on entry day	2	Mass spectrometer off: valve 2 closed (case 3)

TABLE III.- MAJOR ORBITER CONTAMINATION SOURCES[a]

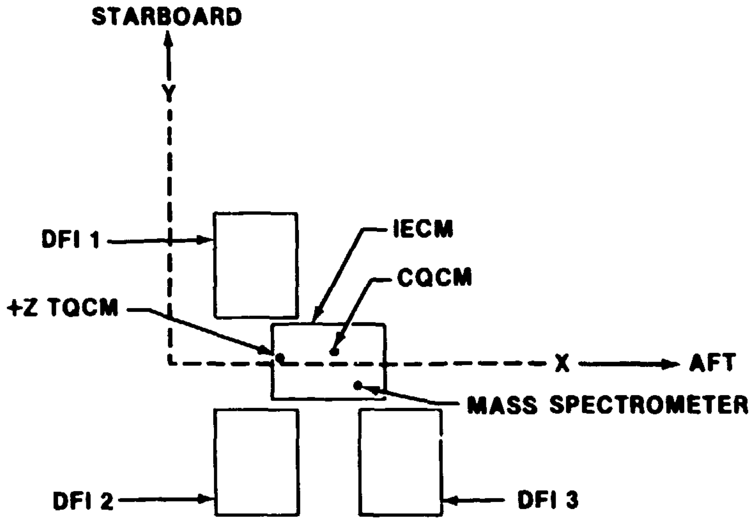
Source	Species	Effluent rate, g/sec	Duration	Time
Early desorption	H_2O, N_2, CO_2, O_2	[b]1×10^{-8} to 1×10^{-11}	Continuous	Continuous
Outgassing	H_2O, N_2, CO_2, O_2	[b]1×10^{-9} to 1×10^{-12}	Continuous	Continuous
Cabin atmosphere leakage	H_2O, N_2, CO_2, O_2	1.84×10^{-2}	Continuous	Continuous
3.9-kN (870-lb) RCS	H_2O, N_2, CO_2, O_2 and MMH-N_2O_4[c]	1420/engine	80 ms to 150 s	As required
0.1-kN (25-lb) VCS		40.8/engine	80 ms	As required
OMS		9798/engine	Variable	As required
Flash evaporator vents	H_2O	4.4	As required	f(rad. T_{in}, T_{out})
Potable (supply) water dump	H_2O	[d]24.5	20 to 25 min	1/day
Waste water dump	H_2O	[d]24.5	10 to 15 min	1/day

[a]Minor Orbiter sources such as fuel cell vents (H_2, O_2) and auxiliary propulsion unit exhaust (NH_3) have low effluent rates and are of short duration.
[b]Units of $g/cm^2 \cdot sec$; rate is a function of material and surface temperatures.
[c]Monomethyl hydrazine - hydrogen tetroxide.
[d]Depends somewhat on flash evaporator usage. Clearing times are about 30 min.

TABLE IV.- MEASUREMENT PREDICTIONS

Source	NCD[a] (LOS1), molecules/cm^2	RF (LOS1), molecules/cm^2•sec•0.1 sr		MS (RF), counts/sec		TQCM (RF), Hz/sec•sr	
		ZLV	Maximum	ZLV	Maximum	ZLV	Maximum
Evaporator	6.6×10^{13}	7×10^{12}	6.3×10^{13}	1×10^5	1.3×10^6	-	-
Outgassing	1.0×10^{10}	1×10^9	2.5×10^{10}	[b]2	[b]50.0	2×10^{-2}	8.0×10^{-2}
Leak	2.0×10^{12}	8×10^{10}	2.4×10^{12}	[c]1×10^3	[c]3.6×10^4	-	-

[a]NCD = molecular number column density.
[b]Maximum peak, 10% of total.
[c]N_2, 76% of total.



VIEW - Z-AXIS
TQCM - TEMPERATURE-CONTROLLED QUARTZ CRYSTAL MICROBALANCE
CQCM - CRYOGENIC QUARTZ CRYSTAL MICROBALANCE

Figure 1.- The IECM and the DFI for the Orbital Flight Test 1 payload (looking downward into the payload bay).

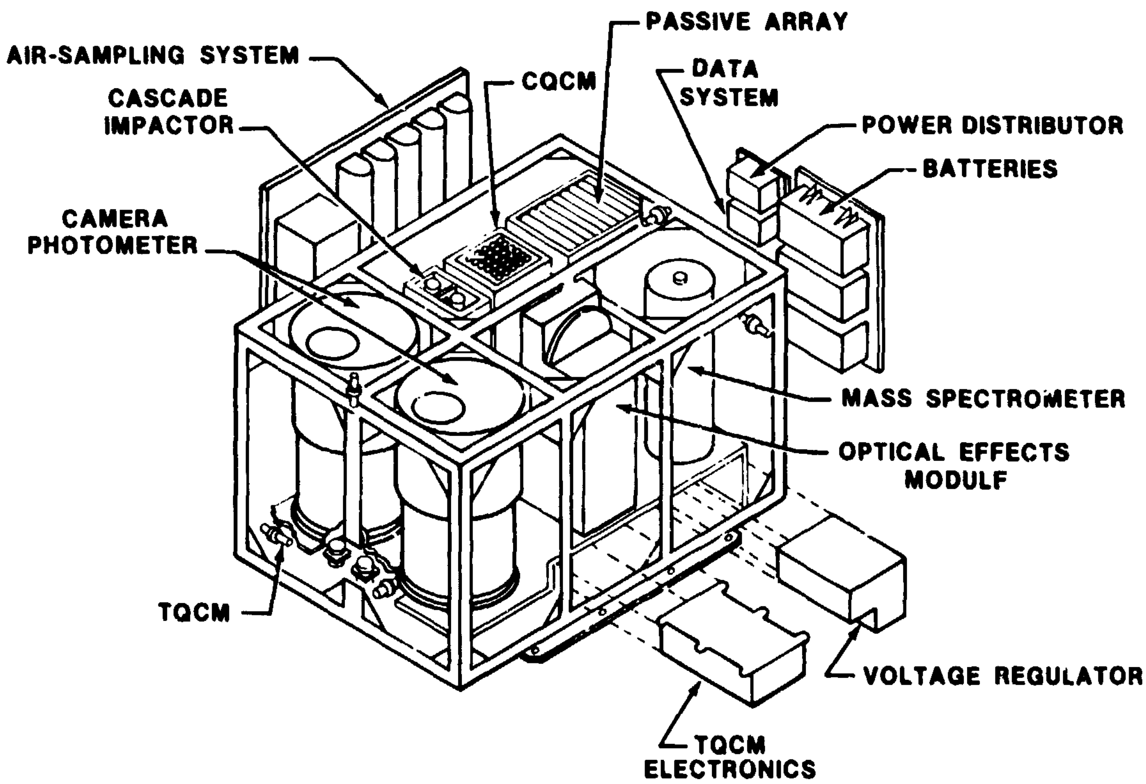


Figure 2.- The IECM.

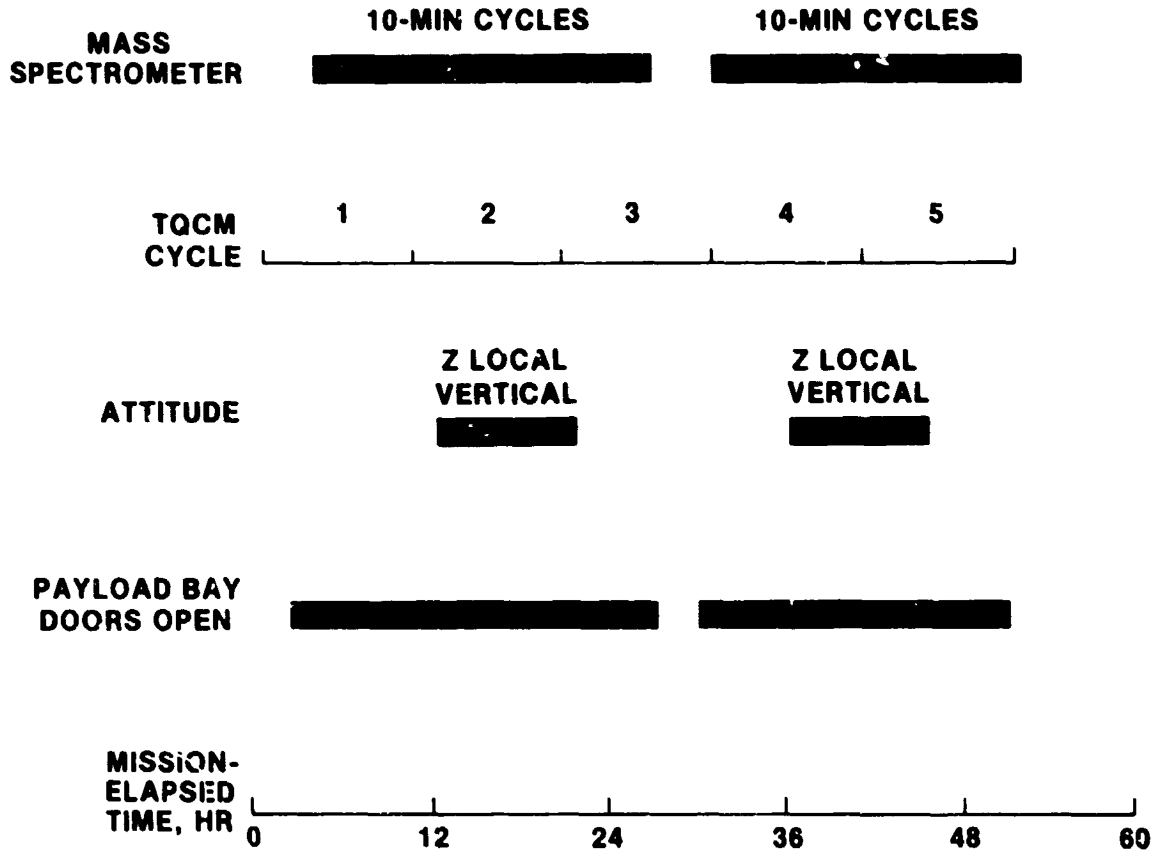


Figure 3.- The STS-1/IECM event time line.

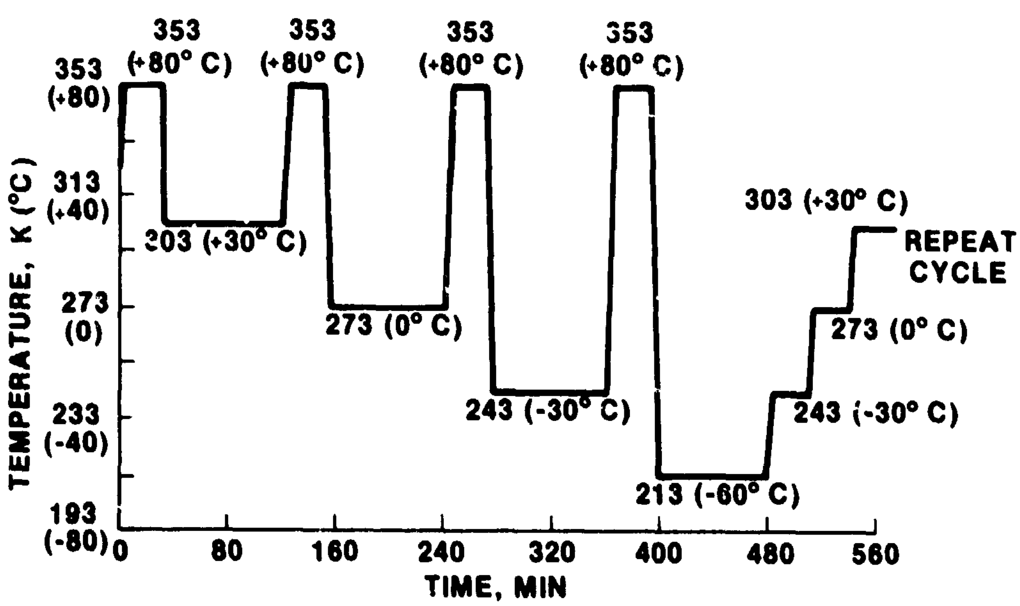


Figure 4.- The TQCM temperature sequence (one cycle).