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CONTROL of ON-ORBIT CONTAMINATION for the ARGOS (P91-1) SATELLITE

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ABSTRACT

The ARGOS (P91-1) satellite presents a challenging combination of on-orbit contamination concerns while mandating a low-cost approach. Several experiment payloads contain contamination sensitive optics, another contains large quantities of CO_2 and Xe for release in orbit, and one contains an NH_3 fueled arc jet thruster. The latter includes a suite of sensors to measure contamination; so prelaunch calculations will be tested. Planned contamination control techniques include: physical separation of sensitive surfaces from contamination sources; flight covers to protect sensitive surfaces during early outgassing on-orbit; gas release and thruster operation early in the flight, before flight covers are opened; and careful control of plumes and venting through a detailed analysis of each.

INTRODUCTION

The Air Force, Space Test Program, satellite ARGOS (Advanced Research and Global Observation Satellite), otherwise known as P91-1, will carry a number of experiments in an 833 km (450 nmi) polar orbit (98° inclination) in 1995. One year of experiment operation is planned, but the vehicle is designed for a three year on-orbit life. The diversity of the experiments presents a number of contamination control concerns; while the nature of the program mandates a low cost approach. This paper presents the contamination requirements and concerns, describes the contamination control approach, and provides an estimate of launch and post launch accumulations.

The current vehicle concept is shown in figure 1. A brief summary of the experiments is provided in table I.

CONTAMINATION CONCERNS and ACTIONS

Contamination Impact

Contamination is of concern primarily for its impact on experiment and vehicle End of Life (EOL) capabilities. For optical instruments, including optical attitude sensors, contamination attenuates the signal by absorbing and scattering the incoming signal, and may increase noise by scattering unwanted radiation into the sensor. Contamination on thermal control surfaces causes an increase in solar absorptivity proportional to the area obscured by particles and the molecular film thickness. The change in emissivity can usually be neglected (ref 1). The radiators will not be sufficiently colder than the rest of the space vehicle that condensation of contaminants is a concern. Molecules will attach to a surface only if polymerized, by solar UV, to form a compound with a much lower vapor pressure (ref 2). Thus, shadowed thermal surfaces are of less concern than sunlit ones. Molecular contamination on solar arrays decreases power (ref 3) as shown in figure 2. The power loss for the expected particle obscuration (~1%) will be negligible (ref 4).

The major contamination sensitivities and EOL requirements, for both the experiments and the space vehicle (SV), are summarized in table II together with the intended precautions. As described below, the ESEX and CIV experiments have much shorter mission lives than the other experiments.

Precautions

On-orbit contamination control, for ARGOS, is achieved by four methods: materials selection, geometry control, flight covers, and time phasing of operations.

All outgassing materials must meet the usual criteria: Total mass loss less than 1% when heated to 125 °C for 24 hours, and collected volatile material on a 25 °C witness plate less than 0.1%. It has been assumed that: 1. the outgassing so measured represents the total loss over mission life; 2. the collected material consists of heavy (~150 amu), polymerizable molecules; 3. the uncollected material is light (~18 amu), non-polymerizable molecules. These assumptions are crude, but are the best values available until the actual materials are defined and measured.

The geometry is shown in figure 3. Emissions, both internal outgas products and thruster plumes, are restricted, in so far as possible, to one end of the vehicle. USA was mounted on the rear to minimize meteor and debris impacts; this required that CIV and ESEX be mounted on the front. The mean free path in the ambient atmosphere is 1600 km; so there are no ram effects. The attitude control thrusters, which share the CIV gas supply, are not shown. In an emergency they will be used to orient the vehicle in a sun-safe mode pending ground intervention. If used, they will emit small CO_2 plumes to the sides; the contamination effects will be negligible. USA has a small leakage of argon with a trace of methane, and the emitting face can be rotated 90° up and down. However, these gasses are noncontaminating, the amount is small, and they do not impinge on the vehicle: they are not a contamination problem.

The optical surfaces of the experiments require a much greater cleanliness than can be economically achieved for rest of the space vehicle. These will be provided with flight covers and controlled internal environments by the experimenters. The covers will remain closed from delivery for integration until favorable conditions are achieved on-orbit, as discussed below. If they must be opened before launch, e.g. for testing, it will be under the direction of the experimenter, who will be responsible for maintaining experiment cleanliness. After opening, the optical elements will not be permitted to view outgassing surfaces, e.g. solar arrays; exceptions will be at the experimenter's risk.

Finally the on-orbit operations have been time phased to limit cross contamination. During phase 1 (two days to two weeks) all experiments will be off, flight covers will remain closed, and no high voltage surfaces will be exposed while the vehicle is checked out and tested. Phase 2 (4-6 weeks) will be devoted to ESEX and CIV operations. The other experiments will remain off, with flight covers closed, and no high voltages will be exposed, except for ESEX operation. Phase 3 will start with a brief (one week) delay to allow any residual thruster effects to disperse. At this point (~ week 8 on orbit) over half of the total outgassing will have occurred and the outgassing rate will be about a tenth of its value at the end of the first day on orbit. Flight covers will now be opened and the operation of the rest of the experiments initiated.

CONTAMINATION SOURCES AND ACCUMULATION

Prelaunch

All exposed surfaces (thermal control surfaces, experiment exteriors, etc) will be cleaned immediately before packing for shipment to the launch site. This cleaning will be to Visibly Clean Level I, which corresponds to an obscuration of 0.5% by particles and less than one microgram/cm^2 (100 Angstrom (A)) molecular film. Thereafter the space vehicle will be protected in a 100,000, or better, cleanroom until launch (122 days); most of this time will be in a class 10,000, or better, environment. This exposure will add 2% obscuration to upward facing surfaces and 0.1% particle obscuration to other surfaces. It will also add 100 A of molecular film to all exposed surfaces. The satellite will be maintained in a vertical position with USA uppermost. There will be some redistribution of large particles by transportation and handling shocks, but these are not expected to significantly increase the particle density on any critical surface.

Ground covers (solar arrays, attitude sensors, ESEX diagnostics) will be removed at payload fairing closure. These surfaces will be visibly clean level I, except for the ESEX diagnostics which will be level II (for definition see below). The prelaunch exposure time for these surfaces will be only five days, which will increase the obscuration of non-upward facing surfaces by 0.004% (no sensitive surface faces upward in this orientation of the satellite). These surfaces will acquire a total of 12 A additional molecular film while covered and during the five days exposure.

Launch/Venting

The payload fairing will be cleaned to Visibly Clean Level II, which corresponds to 0.1% particle obscuration and less than one microgram/cm^2 molecular film. During launch most particles larger than 5 microns will be shaken free and, unless swept out by the vented gas, will redeposit, primarily on the upward facing surfaces. Assuming a two to one area ratio due to the curvature of the fairing, one finds an obscuration increase of less than 0.3% on upward facing surfaces and 0.02% on other surfaces. Molecular film addition will be less than 20 Angstroms due to fairing emissions and and thruster splash. Since there are no cold surfaces to condense molecules and no sunlight to polymerize them, it is assumed that the vented gasses have no contamination effect.

Plumes

ESEX emits 0.25 gm/sec of ammonia (NH_3), nitrogen (N_2, N), and hydrogen (H_2,H). It may also emit trace amounts of contaminants and trace amounts of metallic dust (from the electrodes). There will be ten firings of fifteen minutes each. The experimenter has provided a Monte Carlo analysis showing that most of the emission is confined to a cone centered on the arc axis. Self interaction produces a small amount of backscatter, mostly hydrogen with small amounts of ammonia and nitrogen. This conforms to the expectation that conservation of momentum will cause preferential backscattering of the lightest components. These emissions are not expected to present a contamination problem to the rest of the vehicle.

CIV will release twenty bursts each of carbon dioxide (CO_2) and Xenon (Xe); ten seconds per burst, 100 gm/sec. The gasses will expand, and cool, supersonically (See table III for parameters). It is expected that 75% of the gas will remain within 45° of the vent axis and 95% within 75° (ref 5). The CIV emissions will be very clean, contaminants of concern will be less than one part per million. However, outgas products may be entrained and scattered by the heavy Xe atoms. Also, the CIV plume can produce pressures up to 0.03 Torr or more at points a meter forward of the nozzle. High voltages must not be exposed to these pressures. Pressures at points behind CIV and within enclosures must be calculated on a case by case basis.

Outgassing

The material list is not yet available; so one must make some assumptions to calculate the outgassing. The Tribble and Haffner (ref 3) assumption that the mass of outgassing material interior to the vehicle is equal to one-third the mass of the boxes and wiring, was valid for GPS and appears reasonable for use here for internal emissions. One must also consider external emissions from the Thermal Control Surfaces (TCS) and the solar arrays (adhesives and substrate). Estimates are provided in table

IV. It is expected that outgassing will be completed in less than three years at the temperatures expected.

The outgas effluents of concern, those capable of being polymerized by solar UV, are very heavy molecules, > 150 amu, and their mean free path is long, on the order of meters or more. They will be emitted, with a Lambertian cosine distribution, in straight lines; a threat only to surfaces in line of sight (LOS) of the vent: the shaded side of ESEX and panels two and three of the solar array on that side.

There is one exception to the line of sight rule: the Xenon atoms from CIV may entrain the heavy contaminants and carry them to the ESEX diagnostics. The CO_2 molecules are not heavy enough (44 amu) to significantly divert the heavy contaminants (>150 amu), but Xenon (131 amu) may have some effect. CIV operation may begin as early as the second day ($t=8.6\times10^4$ sec) on orbit. Space vehicle temperature will be about 300 K. The outgas rate formula used by Tribble and Haffner,

$$dm/dt = 3100 \times M_0 \times \mathit{exp}(-5032/T) \;/\; t^{1/2}), \qquad (1)$$

gives a total deposit of about 20 nanograms/cm^2 on the ESEX diagnostics, after 200 seconds exposure (120 exposures, 10 seconds each) if 2% of the incident flux is polymerized.

Each solar array consists of three panels, each 144 cm long. The panels are angled 60° to their rotation axis at a point 17 cm from the vehicle. The first panel is mounted 74 cm from the pivot (figure 4). Panels two and three of the solar array on the vent side are exposed to the effluent when they extend beyond the plane of the vent. For simplicity, the distance and angle to the midpoint of each panel, at its point of closest approach to the vent, was used for the entire area of the panel. Exposure is modified by the cosine effect of the Lambertian emission, the cosine of the angle between the incident flux and the panel normal, and the fractional exposure time. Tribble and Haffner's maximum polymerization factor of 0.008 was used. The calculated deposit is less than 100 nanograms per square centimeter on each panel; this has negligible effect on the power generation when averaged over all six panels.

All solar panels see emissions from the vehicle surface materials. Allowing a *cos* 60° modification of panel area and allowing 0.8% polymerization as before, the total deposit is less than 1000 nanograms/cm^2 for panel 1, 390 nanograms/cm^2 for panel 2,and 210 nanograms/cm^2 for panel 3. Combining this with the deposit from the vented material gives no more than a microgram/cm^2 for any panel and little impact on the total power output.

The vehicle thermal control surfaces, and the radiator on the sunlit side of ESEX will be exposed to outgas products from the solar arrays.

Totaling the emissions from the three panels (with proper distances for each), including a 60° factor for Lambertian emission, and using a polymerization factor of 2%, one finds deposits up to 1.6 micrograms/cm^2. This corresponds to an absorptivity increase of 0.008. Note that minimum distances were used and the receiving surfaces were assumed to be perpendicular to the line of sight; both cause overestimation of the effect.

SUMMARY

The objective is to provide low cost contamination control for a satellite with diverse experiments. This is done by controlling materials, controlling the locations and fields of view of the experiments, using flight covers over the optical surfaces, and time phasing the on-orbit operations. The results are summarized in table V. All requirements are satisfied with adequate margins. Given the added consideration of the conservative nature of the approximations, the margins become very comfortable.

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Table I ARGOS EXPERIMENTS		
EXPERIMENT	SOURCE	INSTRUMENT/TECHNIQUE
CIV ESEX	USAF/Phillips Lab USAF/Phillips Lab	Critical Ionization Velocity; CO2 and Xe Release Arcjet Propulsion; NH3 Propellant
EUVIP	Army	EUV Imager
GIMI HIRAAS USA	NRL NRL NRL	Far UV Cameras Extreme and Far UV Spectroradiometer Stellar X-Ray Observation
ADCNS	DARPA	Attitude & Navigation; Celestial Star Tracking
SPADUS	ONR	Space Dust Measurement

Table II CONTAMINATION CONCERNS AND PRECAUTIONS			
ELEMENT	CONCERN	PRECAUTION	EOL REQUIREMENT
CIV	Orifice Blockage, Gas Cleanliness	Use Hydrazine Spec for Components	*<20 ppm Emitted Contamination
ESEX -Diagnostics -Radiator	Sensor Background Absorptivity	Ground Cover, Clean Before Launch	*Δm <5 μ gm/cm2 *$\Delta\alpha$ < 0.08
EUVIP GIMI HIRAAS ADCNS	Throughput Loss	Flight Covers, No LOS to SV	Experimenter Determined & Controlled
USA SPADUS Shaded TCS	None	Not Applicable	Not Applicable
Sunlit TCS Solar Arrays Attitude Sensors	Absorptivity ** Loss of Illumination Loss of Throughput	Limit Venting, Clean before Launch Ground Cover	$\Delta\alpha$ <0.08 ΔP/P < 0.02 Throughput Loss < 20%
* EOL = End of Phase 2; ** Contamination Driver			

Table III CIV EXPANSION PARAMETERS						
SPECIES	MASS	VELOCITY	TEMP	<--1 m from release -->		
				DENS	PRESS	MFP
	amu	cm/sec	K	#/cc	Torr	cm
CO2	44	6.9x104	137	1x1017	1.5	1x10-3
Xe	131	3.1x104	118	8x1016	1.0	2x10-3

Table IV OUTGASSING ESTIMATES			
SOURCE	MASS	OUTGAS	
		TYPE	MASS
	grams	amu	grams
Internal	2.4x105	18 150	2100 240
TCS	3.4x104	18 150	310 34**
SA	4.2x104	18 150	380 42**
** TCS and solar array are expected to emit much less than 0.1% of their mass as polymerizable material			

Table V ADDED CONTAMINATION (obscure/film) AND IMPACT						
SURFACE	PRE-LAUNCH	LAUNCH	POST-LAUNCH	TOTAL	IMPACT	MARGIN
ESEX	4x10-5 3 Ang	2x10-3 100 Ang	0.3 Ang	2x10-3 100 Ang	Δm=2.1 μg/cm2 $\Delta\alpha$=0.021	1.4 2.8
Sunlit TCS	1x10-3 80 Ang	2x10-3 100 Ang	500 Ang	3x10-3 680 Ang	$\Delta\alpha$=0.025	2.2
Solar Arrays	4x10-5 3 Ang	2x10-3 100 Ang	150 Ang	2x10-3 250 Ang	ΔP/P= 0.009-0.012	0.7-1.2
Attitude Sensors	4x10-5 3 Ang	2x10-3 100 Ang	---	2x10-3 100 Ang	1.7% Loss	11

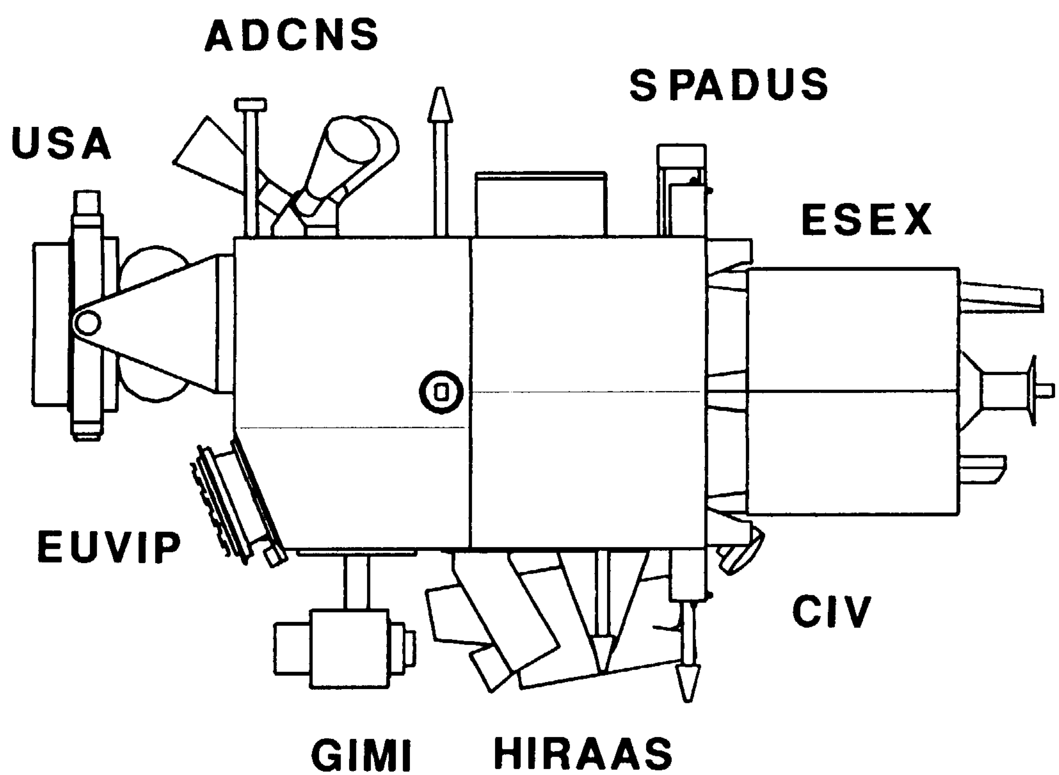

Figure 1 ARGOS vehicle with experiment locations. Solar arrays have been omitted for clarity.

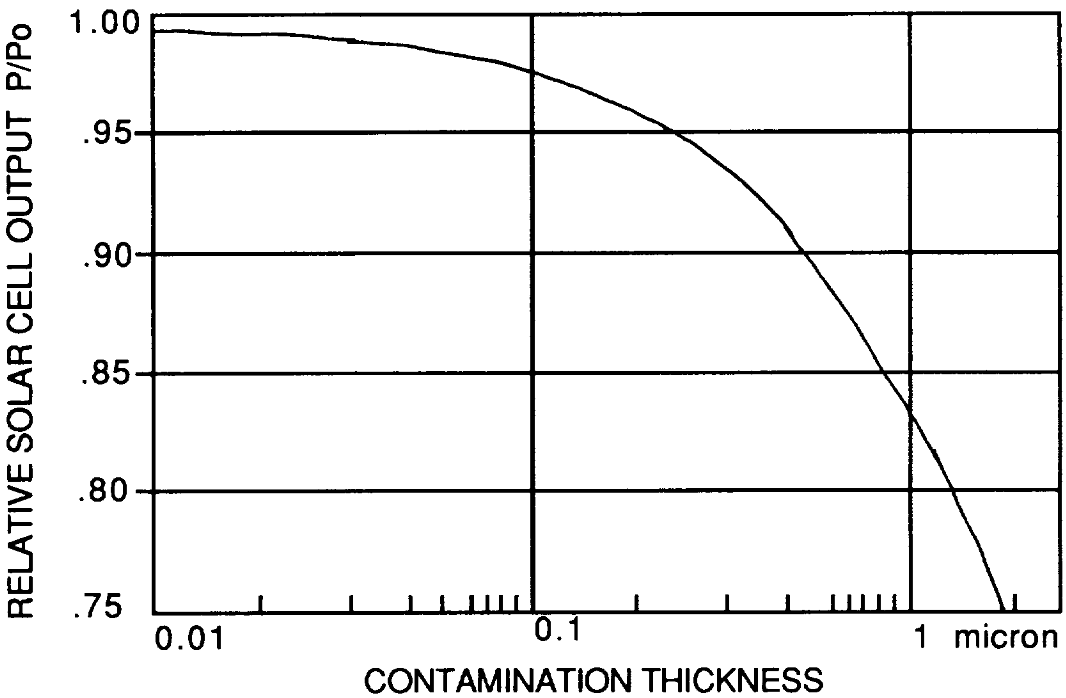

Figure 2 Solar Array Power is a function of molecular film thickness (It was assumed that 0.01 microns is equivalent to one microgram per square centimeter).

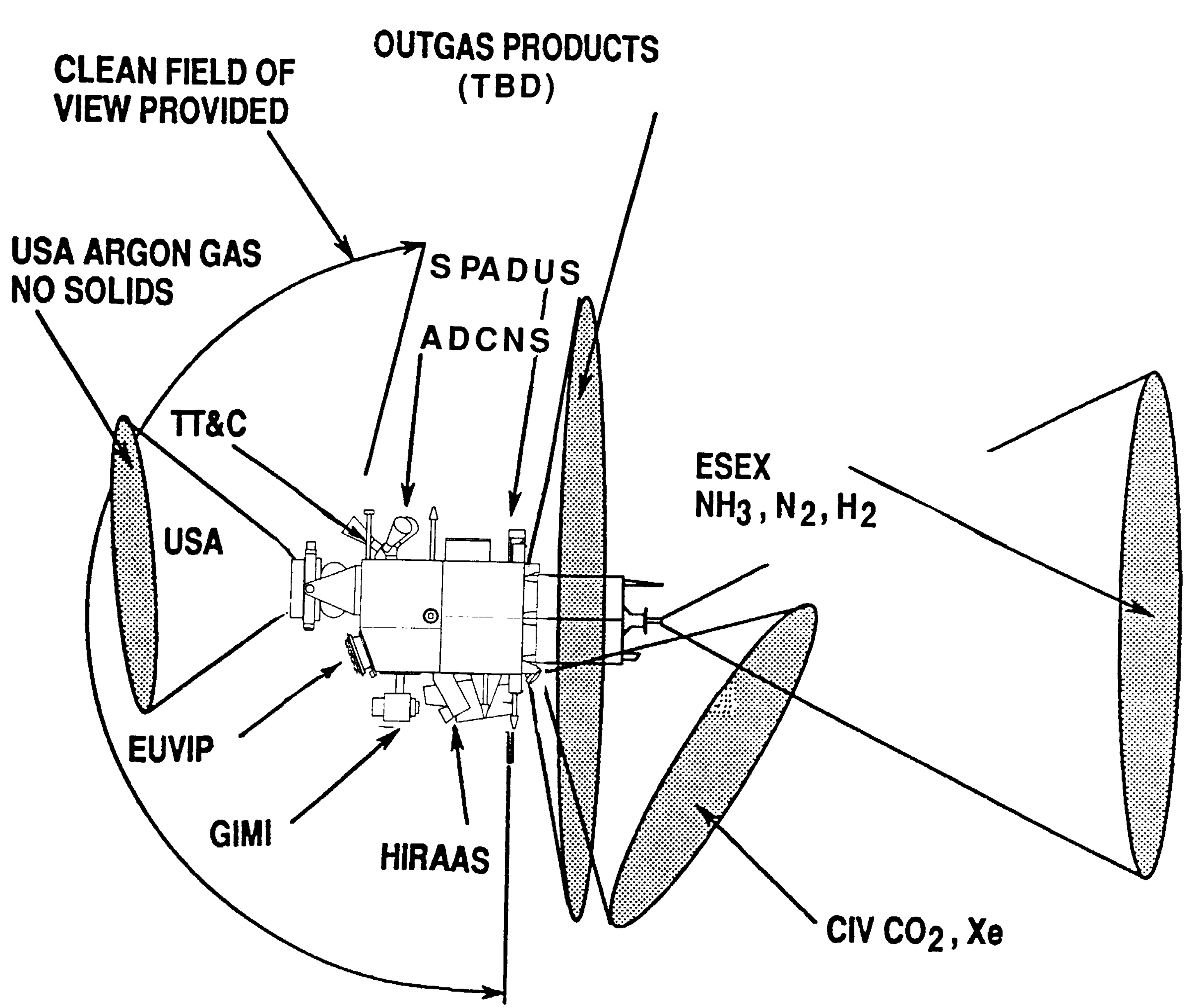

Figure 3 Sensitive surfaces are located as far as possible from contamination sources and do not view them.

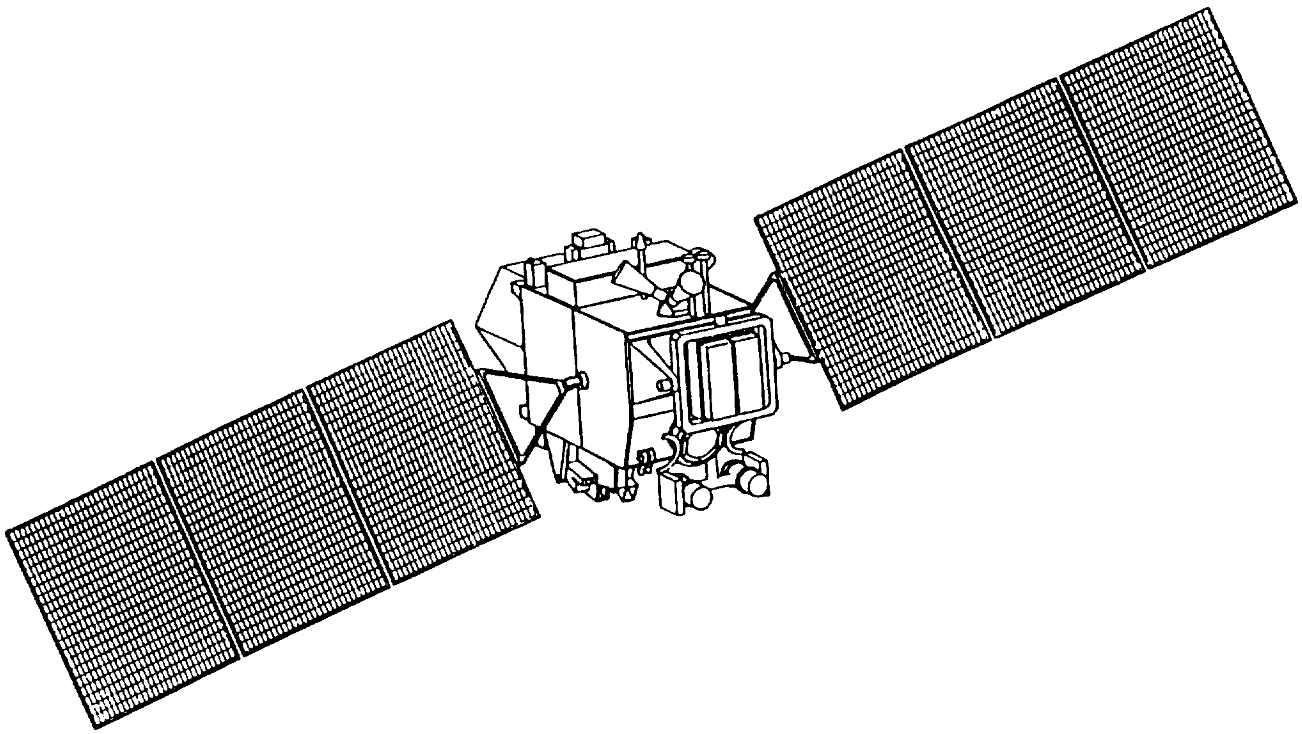

Figure 4 Each solar array is angled 60° to the rotation axis for the array.