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REDISTRIBUTION OF PARTICULATES IN SHUTTLE BAY DURING LAUNCH

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ABSTRACT

The dislodgement, venting, and redeposition of particles on a surface in the shuttle bay by the vibroacoustic, gravitational, and aerodynamic forces present during shuttle ascent have been investigated (ref. 1). The particles of different sizes which are displaced, vented, and redistributed have been calculated; and an estimate of the increased number of particles on certain surfaces and the decrease on others has been indicated. The average sizes, velocities, and length of time for certain particles to leave the bay following initial shuttle doors opening and thermal tests have been calculated based on indirect data obtained during several shuttle flights. Suggestions for future measurements and observations to characterize the particulate environment and the techniques to limit the in-orbit particulate contamination of surfaces and environment have been offered.

ANALYSIS RESULTS AND CONCLUSIONS

Particulate contaminants on shuttle bay surfaces and on surfaces of payloads carried by the shuttle will be resuspended during shuttle ascent by vibroacoustic, gravitational, and aerodynamic loadings.

Random mechanical accelerations of about 13 g rms in the frequency range of 20 to 2000 Hz experienced during ascent by surfaces and systems are expected to release from surfaces all the particles in excess of 80-90 μm diameter and only 1-2 percent of particles less than 10 μm. These particles--depending on the direction of the releasing surface with respect to the acceleration vector--will fall back on the surface, fall on another surface properly positioned with respect to the velocity vector, or be transported to the vent filters. Also, if they have sufficient falling kinetic energy, they may bounce from surface to surface until they either deposit on a surface or are entrained by the outgassing molecules in the bay acquiring the energy of the outgassing molecules which will be colliding with them. The particles not deposited will be moving randomly in this relatively tenous gas only rarely hitting a surface.

Two periods of releasing and resetting of particles are envisioned. During these two periods, the random acceleration forces have magnitudes of about 13 g rms including some peak magnitudes of about 39 g.

An initial number of particles will be released during the initial 2 minutes of ascent while venting of the bay volume is occurring. During the transonic region of flight with maximum mechanical disturbance at the surfaces and maximum vent velocity in the bay, released particles of less than about 58 μm, will be entrained by the gas flow. Most of them may be directed to the vents where they are trapped if greater than about 35 μm. Others entrapped in a turbulent flow will remain in random motion in the bay.

Released particles greater than 58 μm will resettle on the surface of origin if the surface is normal and facing the velocity vector. Those released from surfaces parallel and/or not facing the velocity vector will drop on surfaces facing the vector by virtue of the shuttle acceleration.

During the second stage of the ascent, which terminates about 9 minutes after launch, additional particles are released and resettled. Aerodynamic drag in the bay is no longer effective in moving particles; and those released either will be accommodated on the surface by the shuttle acceleration or will be floating about in the bay in a zero g environment.

The following particle redistributions may be expected during launch in the shuttle or in an instrument:

- A surface facing opposite the acceleration vector at a prelaunch cleanliness level of 750 as per MIL-STD 1246A will lose particles as it cleans up (fig. 1).

  In orbit, that surface will have slightly less particles in the size range up to 36 μm and considerably less particles of larger size than it had at launch. No particle greater than about 90 μm will be left on that surface.

- A surface looking into the velocity vector and located toward the rear recovers its own acceleration released particles and collects particles released from other surfaces which are accelerated toward the rear of the shuttle or of the instrument (fig. 2). The increased number of particles on these surfaces are mainly those of diameter greater than 58 μm. The number of particles per unit area may double for this range if there is a one-to-one view factor between the rejecting and accepting surfaces. If the area of the surfaces releasing particles is K times the area of those surfaces receiving particles, then the accommodation is approximately K times the one for the one-to-one view factor. For the shuttle bay, the distribution per unit area on the aft surface of the bay may be approximately 18 times that for the double distribution obtained for the one-to-one view factor.

- A relatively clean surface (less than Level 500) will be contaminated with particles from other surfaces greater than 58 μm, and with few particles with diameters between 58 and 5 μm (fig. 3).

- The redistribution of particles on surfaces assumed to have an initial distribution of particles corresponding to Level 750, with a surface correspondence of a one-to-one, has been indicated. These assumptions can be changed since the losses and gains of particles are provided in terms of the percentage of particles per unit area in the specific particle size range. The gain on a unit surface can be estimated by modifying the results for a one-to-one relation by the area ratio of the surface losing to the one gaining particulates.

- Some small particles <58 μm, which did not enter the vents or were released during the second phase of acceleration, are entrained in the outgassing molecules and move randomly in the bay where the outgassing mean free path is a few tens of cm. After about 2 hours in orbit when the bay doors are opened, those particles which have mean diameters of 10-15 μm leave the bay with average velocities of about $1x10^{-2}$ cm/s. Outside of the bay, these particles are decelerated with respect to the orbiter by drag forces and will be moving away from the velocity vector. The camera-photometer observing these particles at various distances from the bay will see the particle moving at about 1.5 m/s if the particle is 20 m away and about 0.33 m/s if at 1 m away. These bay released particles lose energy with respect to the shuttle and enter a different orbit.

- Particles of mean diameter of about 36 μm which had deposited on surfaces and/or did not leave the bay will be made to leave the bay at velocities of $1.5x10^{-3}$cm/s by thermally induced effects. Thermal shock, differential thermal expansions, friction between surfaces, photodesorption, thermophoresis, desorption from surfaces, and other mechanisms can be the cause of these additional emissions, which have been observed by the camera photometer in one of the shuttle flights.

RECOMMENDATIONS

1. Clean the bay surfaces and payloads to optimum level of cleanliness before launch. Protect the clean surfaces whenever possible.

2. Surfaces normal to the acceleration vector should be as clean as possible, since they will receive additional particles from other surfaces above them not facing the acceleration vector.

3. The bay doors should be opened as soon as possible to allow particles floating in the bay to exit. This will limit the settling of those particles on surfaces.

4. Provide particulate shields, covers, and doors on surfaces normal to acceleration. The covers should firmly enclose the protected surface preventing particles carried by turbulent venting flow from entering the spacing between cover and surface.

5. Optical observations out of the bay should be carried out after the source of particles leaving the bay is depleted. The time constant (1/e drop in number) is about 10-15 hours. The time to wait for the number of particles leaving the bay to be a few percent of the initials is therefore 40-50 hours after bay opening. This delay in observation may also be necessary after an initial thermo-shock of the shuttle bay.

6. Suggested measurements and data collections which may provide additional understanding of the release and redistribution of particles in the bay are:

   a. Photomicrograph control surfaces located on bulkhead and aft of the bay, before launch, after rocket boosters' separation (2 min), after tank separation. Analyze these photos for particles redistributions as a function of ascent stages.

   b. Analyze the particulates on a filter vent before launch and in orbit. The sample filter could be replaced in orbit and returned to ground in a protected enclosure.

   c. Inspect and check visually for particulate deposits in the aft bay and bulkhead after shuttle flights to note gross differences in deposits.

   d. Use particle deposition instruments located at strategic locations in the bay and timed to operate at specific periods of the ascent to provide particulate density data in the bay at various times.

   e. Use QCMs with sticky surfaces to collect particulates at various bay locations during ascent.

   f. Use optical systems to get data on particulate density in the bay as a function of time while bay doors are closed and when opened.

REFERENCES

1. Scialdone, J. J.: Particulate Contaminant Relocation During shuttle Ascent, NASA TM-87794, June 1986.

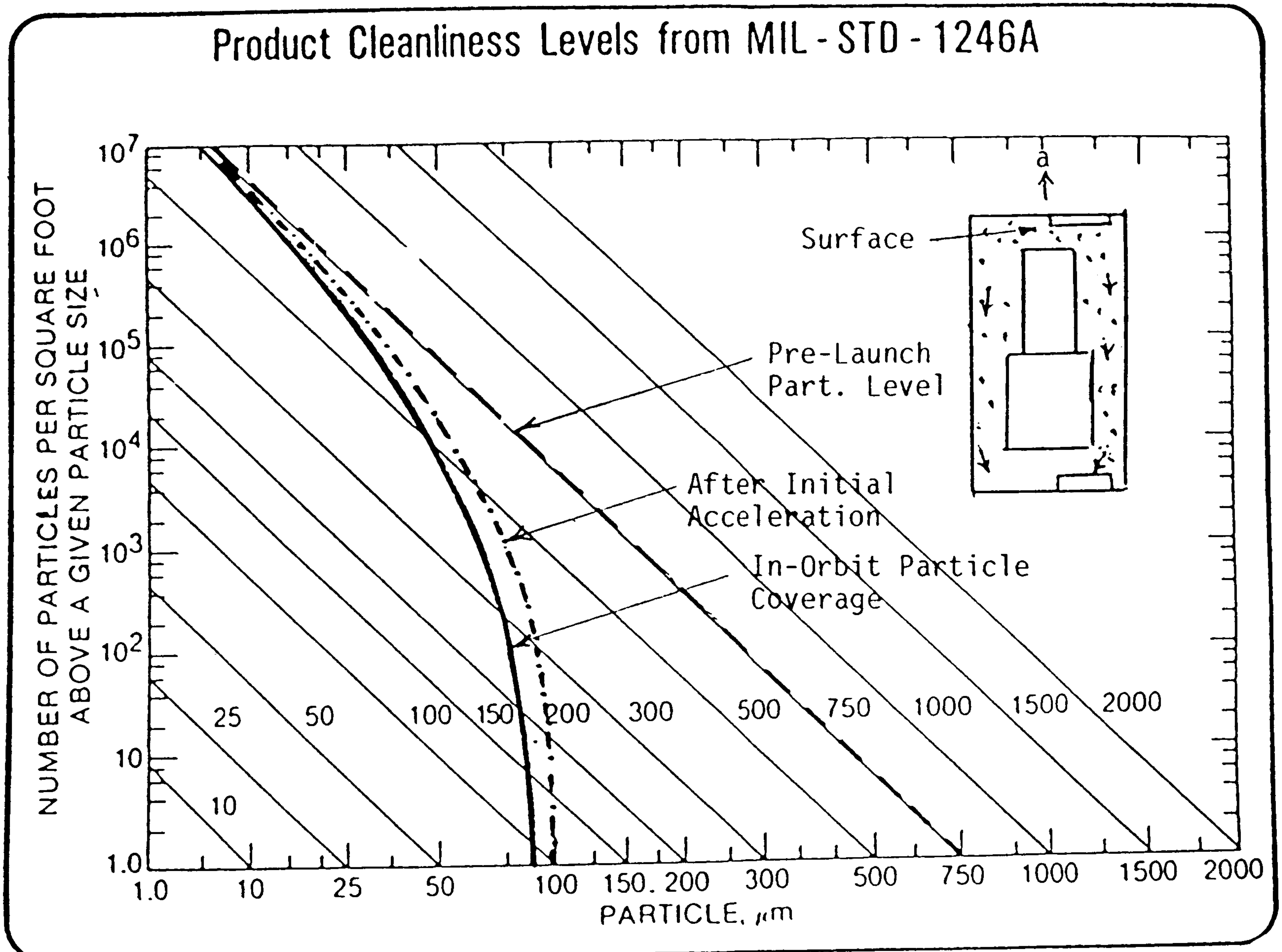

Figure 1. Particles depletion during shuttle ascent from a surface not facing the acceleration vector, contaminated to A Lv 750 of MIL-STD-1246A

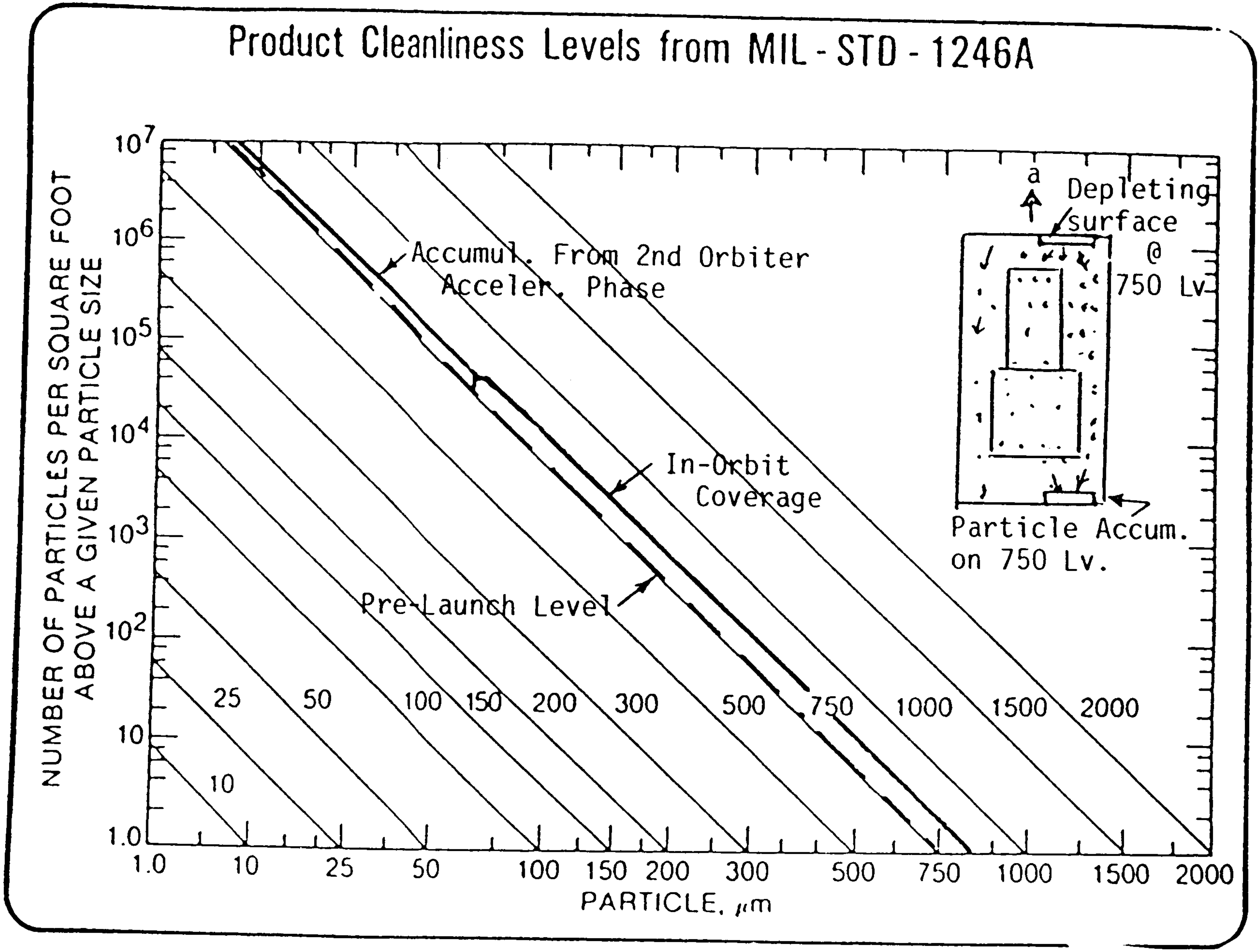

Figure 2. Particles accumulation during shuttle ascent on a surface facing the acceleration vector at a pre-launch Lv 750 from a depleting surface also at 750 Lv with a one-to-one field of view

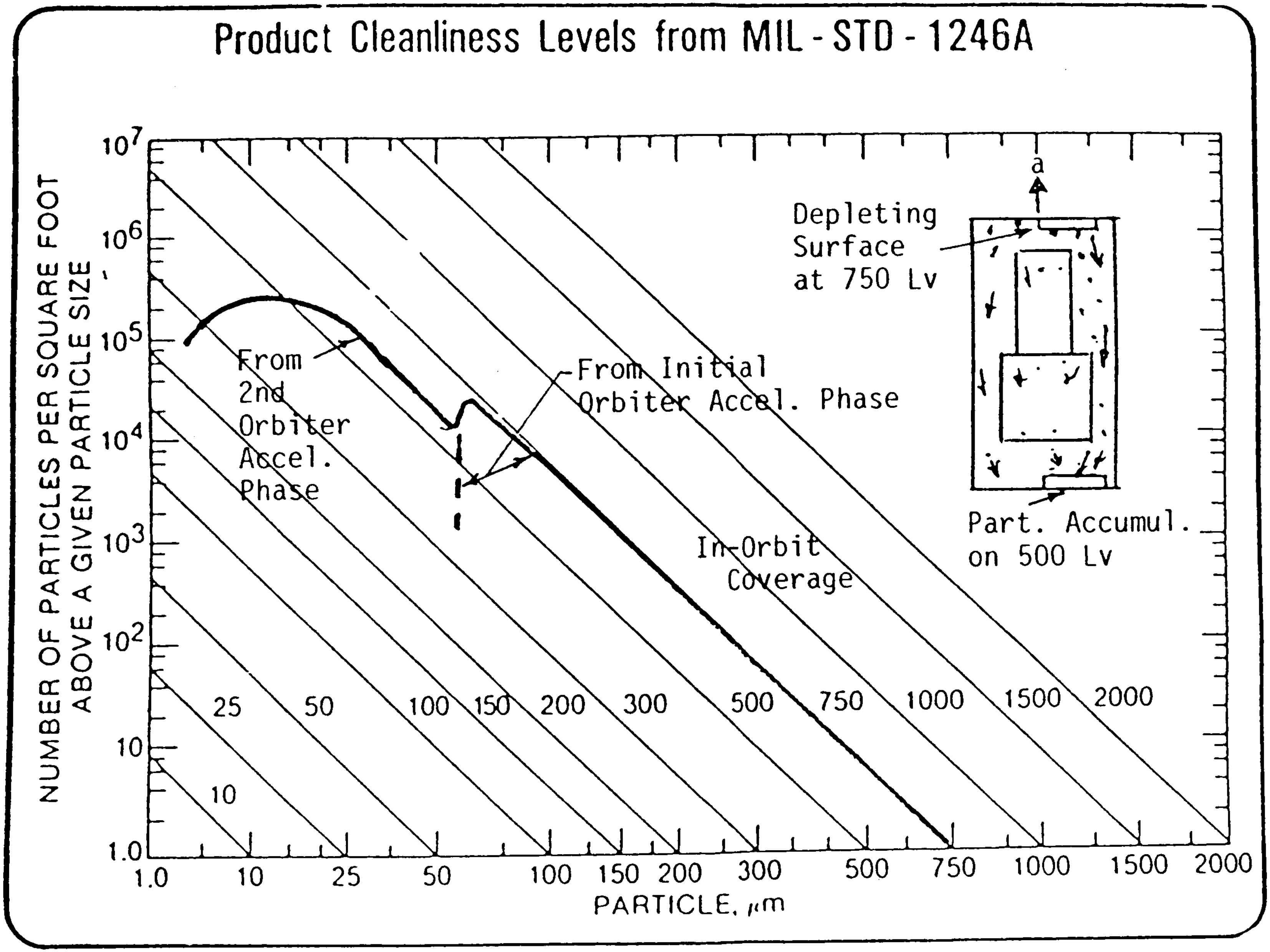

Figure 3. Particles accumulation during shuttle ascent on a clean surface (pre-launch Lv 500) facing acceleration from a depleting surface at Lv 750 with a one-to-one field of view