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EDRS-C CONTAMINATION MEASUREMENT AND CONTROL

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I. INTRODUCTION

Optical instruments, sensitive to contamination, impose stringent cleanliness requirements for spacecraft missions. The contamination aspects and the subsequent possible performance degradation of the optical instruments have to be considered and controlled all along the spacecraft manufacturing and operative life.

OHB System AG developed methods, processes and procedures in order to measure, control and predict On-ground and In-orbit contamination.

This paper presents the contamination control and analysis, carried out in the frame of the EDRS-C mission, in order to meet the stringent performance requirements imposed by its optical payload.

II. EUROPEAN DATA RELAY SYSTEM / EDRS-C

The primary objective of the EDRS mission is the construction of a European Data Relay System (EDRS), which will provide a data relay services from GEO orbit to LEO satellites. The constellation is formed by two satellites.

OHB System AG is responsible for one of these two satellites: EDRS-C.

EDRS-C is developed on the basis of the SmallGEO platform, designed and manufactured by OHB System AG. EDRS-C accommodates on its earth-deck an Optical Payload, the so called Laser Communication Terminal (LCT), designed and manufactured by TESAT Spacecom GmbH & Co. KG.

The LCT establishes and maintains an optical communication link together with an LCT counterpart on a suitable target LEO satellite. The Data Relay Payload shall then guarantee the transmission of the data to the ground.

EDRS-C is designed for a lifetime of 15 years.

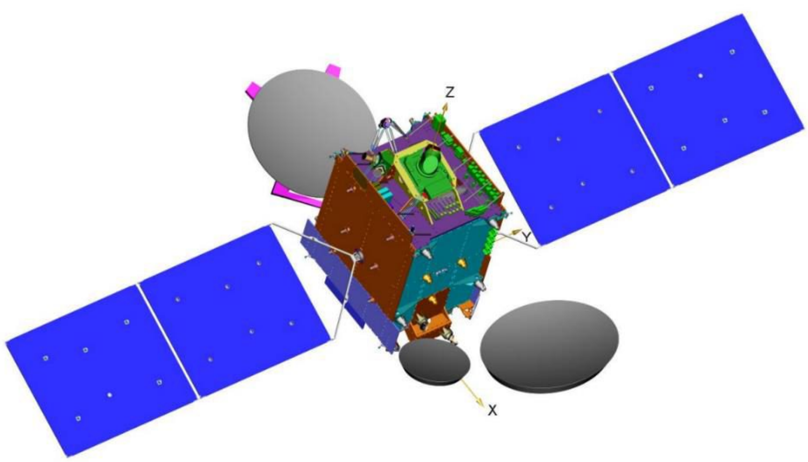

Fig. 1. EDRS-C

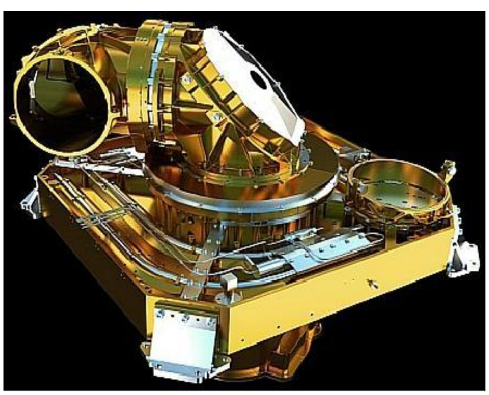

Fig. 2. TESAT Spacecom LCT embarked on EDRS-C

III. ON-GROUND CONTAMINATION CONTROL

In response to the EDRS requirements, OHB System has established a control plan, an on-ground budget and procedures to maintain the cleanliness and contamination level for the EDRS-C flight hardware during manufacturing, assembly, integration, test and transportation up to launch.
The control plan identifies:

- the sensitive items and level of sensitivity,
- the possible failures and malfunctions due to contamination,
- the verification and monitoring flows.

The on-ground budget estimates the expected molecular and particulate contamination levels generated during the MAIT (Manufacturing, Assembly, Integration and Testing) activities and launch phase.
The procedures provide guidelines:

- for cleanliness control,
- to maintain and consolidate the estimated contamination levels,
- to prevent any performance degradation.

A. Sensitive Elements – LCT Optical Surfaces

On board on EDRS-C, the LCT Optical Surfaces are the driving elements of the Satellite contamination control.
The LCT manufacturer TESAT allocated a budget for the OHB on ground contamination from the LCT delivery up to the launch that is reported in Table 2. If these conditions are met, then the contamination will not have an impact on the LCT performances.
The LCT supplier helps OHB System in the estimation of the LCT on ground contamination budget from the LCT delivery up to the launch pad.
The LCT design is such that the optical surfaces are protected as much as possible, such that the sensitivity of the LCT with respect to contamination is minimized. This is reached by a design that encloses all the sensitive optical surfaces inside the LCT.
When the LCT is open (configuration shown in Fig. 2), the outer mirror is fully exposed to the (ground or space) environment. Therefore dedicated protections and corrective actions have to be adopted during the AIT and launch phases, in order to reduce the contamination on the optical surfaces to acceptable levels.
The contamination budget allocation reported in Table 2 is accounted on the LCT outer mirror.
The LCT is delivered locked by a special device in the closed launch position and equipped with an aperture/closure cap and a dust cover. In this configuration, the outer mirror and the LCT optics are protected against contamination during non-operational modes.
In addition, TESAT will supply ground support equipment for continuously purging the inner volume of the LCT by dry N2 of a quality 5.0 or better. The LCT shall be purged whenever possible.
TESAT provides very detailed handling and storage procedures to prevent contamination issues. In general, the LCT shall only be handled in controlled environment compatible ISO 8 class or better, every removal of one of the protection and every interrupt of nitrogen supply shall be recorded (duration and equivalent clean room class) in an event log and considered in the dedicated budget. Condensation has to be strictly avoided. Personnel shall wear face-masks, hairnets and lint-free gloves suitable for clean room ISO 5. Processes that may produce contamination have to be avoided near the LCT. OHB System AIT personnel will be carefully instructed and trained to follow the dedicated procedures established upon TESAT recommendations.
Apart the dust cover, all the other protection devices against the contamination are compatible with almost all the tests performed during the AIT phases and the environmental test campaign. Therefore, the protection shall be removed only when strictly necessary and as late as possible just before the test starting and launch. The table 2 summarizes the no flight hardware test compatibilities.

Table 1. No flight hardware test compatibility.

	AIT	EMC	TVAC	Mechanical
Aperture Closure Cap	Yes	Yes	Yes	No
Purging System	Yes	No	Yes	No
Lock device	Yes	Yes	Yes	Yes
Dust Cover	Partially	No	No	No

During the TVAC (Thermal Vacuum Chamber), it shall be ensured that LCT is never the coldest spot in the vacuum chamber. In addition the purging is required during the pump down until the chamber reaches the pressure of 10^{-3} hPa and during the whole duration of the re-pressurization.

B. Assumptions and On-Ground Contamination Budget

Based on the precaution reported above, a considerable number of assumptions have been made. The assumptions define the different cleanliness class for the LCT optical surfaces for PAC (Particulate Contamination) and MOC (Molecular Contamination) contamination. As outcome of these assumptions, a contamination budget has been established for the on-ground contamination of LCT optics. It takes into account the different AIT phases in different environments up to the launch, with corresponding exposure times, protections, surface orientation and transportation condition. It verifies that the cleanliness requirements, derived from the analytical assumptions can be met.
The budget has been prepared by TESAT in collaboration with OHB System. The cleanliness classes have been given in both notation: ISO 14644 and FED-STD-209.
The PAC budget has been obtained calculating:

1. the surface cleanliness level against the exposure time and the clean room class according to [5] and [7]
2. the surface coverage according to [2] and [6]. The surface coverage related to a certain cleanliness level has been obtained analytically by a log – log2 law. Exposition times of surfaces to different cleanroom conditions are added up separately, and then cleanliness level and surface coverage are obtained for each cleanroom class. The coverage is summed up in the end.

The MOC budget has been performed according to [7]. The model assumption for the MOC budget performed by TESAT for the LCT external environment assumes a MOC rate less 200 ng/cm2 per year.
The Table 3 below summarizes the PAC and MOC budget results for the LCT Outer Mirror.

Table 2. LCT Outer Mirror Budget (u: surface facing upwards / d: surface facing downwards)

<table>
<tr><th colspan="8">LCT Outer Mirror</th></tr>
<tr><td rowspan="5">PAC</td><td>Clean Room Class</td><td>10</td><td>100</td><td>1000</td><td>10000</td><td colspan="2">100000</td></tr>
<tr><td>Hours</td><td>0 (u)
34363 (d)</td><td>16 (u)
7733 (d)</td><td>0 (u)
881 (d)</td><td>0 (u)
310 (d)</td><td colspan="2">3 (u)
31.9 (d)</td></tr>
<tr><td>Surface Coverage [ppm]</td><td>7.1</td><td>5.0</td><td>2.6</td><td>4.3</td><td colspan="2">31.7</td></tr>
<tr><td>Total Surface Coverage [ppm]</td><td colspan="6">50.7</td></tr>
<tr><td>Limit at Launch Pad [ppm]</td><td colspan="6">75</td></tr>
<tr><td rowspan="5">MOC</td><td>Molecular contamination level</td><td>A/100</td><td>A/50</td><td>A/20</td><td>A/10</td><td>A/5</td><td>A/2</td></tr>
<tr><td>Hours</td><td>34363</td><td>7733</td><td>897</td><td>294</td><td>19</td><td>32</td></tr>
<tr><td>Molecular Contamination [ng/cm2]</td><td>39.20</td><td>17.64</td><td>5.12</td><td>3.35</td><td>0.43</td><td>1.82</td></tr>
<tr><td>Total Molecular Contamination [ng/cm2]</td><td colspan="6">67.6</td></tr>
<tr><td>Limit at Launch Pad [ng/cm2]</td><td colspan="6">100</td></tr>
</table>

According to the results, the levels of molecular and particulate contamination are within the allocated margin and the LCT reaches its specified performance with sufficient margin.
PAC and MOC predictions are supported by measurements inside the specific integration and test areas. The last measurements indicate that the MOC rates are below the ones assumed by TESAT in the budget and the PAC rates are below the yearly values reported in the ECSS [1].
EDRS-C satellite will be mainly integrated and tested in ISO8 class clean rooms.
As described in the section below, these figures have to be confirmed by tests during the activities.

C. Cleanliness Control Flow Chart

As outcome of the on ground contamination prediction, a cleanliness control flow chart has been established by OHB System. The aim of this Flow is to identify check points, the so called Cleanliness Inspection Point (C.I.) to reconcile the predicted budget and allocation with the measured levels of PAC and MOC.
The AIT activities up to launch will be constantly monitored. Monitoring methods and frequencies are described in Table 4.

Table 3. Envisaged cleanliness verification frequencies

Method	Verification	Frequency
Airborne Particles Monitoring	PAC	Continuously
Visual Inspection	Cleanliness	Key and Mandatory Inspection Point
Contamination Witnesses	PAC	Every two weeks and/or at C.I.
	MOC	Every two months and/or at C.I.
	MOC	TQCM during TVAC

At the Cleanliness Inspection point the PAC and MOC witness samples will be checked and the contamination levels will be compared with the values predicted in the Contamination Budget, in order to evaluate its consistency.
In order to monitor the contamination in horizontal and vertical direction, two witness samples per each type (PAC and MOC) will be put close to the LCT.
The Cleanliness Control Flow has to be consolidated by the SAT IRR.

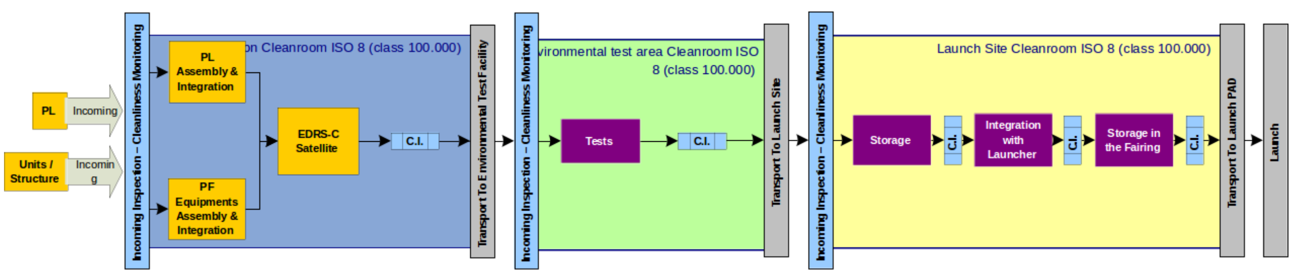

Fig. 3. Cleanliness Control Flow Chart

IV. IN ORBIT OUTGASSING ANALYSIS

Since the launch of first optical satellites, contamination of sensitive items appeared as a serious threat to the mission success. Once in orbit, it is very difficult to save a satellite mission if sensitive items are deeply impacted by contamination.
Therefore, modelling and simulating the contamination is a necessity in order to avoid flows in the design of the satellite such as vicinity of sensitive items to the thrusters or use of high outgassing materials that can lead to a significant EOL (End of Life) transmission loss.
This section will focus on the outgassing modelling and simulation since chemical thrusters are not a threat to the LCT.
The LCT molecular contamination allocation after 15 years orbit that guarantee no performance degradation is reported in Table 5. These values are the outcomes of the first OHB Contamination Analysis results and the iteration with the LCT supplier.

A. ERDS-C Outgassing modelling and simulation

Outgassing occurs when molecules leave the material surface by desorption. These molecules can deposit on surfaces modifying their optical properties. Each material has a fraction of potentially ejectable molecules that can be grouped by TML (Total Mass Loss), RML (Recovered Mass Loss) and the CVCM (Collected Volatile Condensable Material).
According to [1], the use of materials in space have to respect TML < 1%, RML < 1% and CVCM < 0.1%. This requirement helps material engineers for carefully choosing their materials especially in the vicinity of the sensitive items.
However, these data do not give an idea about the kinetic of outgassing. In fact, in order to estimate the deposit at EOL on a surface, the dependency on the surface temperature and the mission timeline need to be modelled.

In the frame of EDRS, the Outgassing simulation has been carried out with the software SYSTEMA/Outgassing [8]. This software computes the view factors between satellites nodes and then, calculates the cumulated mass deposit based on time residence approach.
The “Emission/Reemission” time residence approach has been developed by ESA/ESTEC in [9]. Each outgassing species (k) have its own time residence before getting emitted from the surface. This residence time takes into account surfaces temperatures (T), materials mass and thickness (h). The reference residence time is derived from tests carried on by ESTEC. The same approach is used for the reemission [10].

For example, Table 1 shows the kinetic outgassing parameters for the RTV that have been used in the simulation.

Table. 4. Silicone RTV kinetic outgassing parameters

<table>
<tr><th>Material</th><th>Test Reference</th><th>Number of Species.</th><th colspan="2">$\tau_{e,0}$ (m)</th><th colspan="2">T_0 (˚C)</th></tr>
<tr><td>RTV_S691</td><td>VBQC-3617</td><td>6</td><td colspan="2">8.00E-05</td><td colspan="2">25</td></tr>
<tr><th>Species Name</th><th colspan="2">W0 (%)</th><th>$\tau_{e,k}$ (hours)</th><th>Ke (K-1)</th><th>$T_{r,k}$ (hours)</th><th>Kr (K-1)</th></tr>
<tr><td>RTV_A</td><td colspan="2">0.00317</td><td>0.012</td><td rowspan="6">-0.0554</td><td>7.52E-04</td><td rowspan="6">-0.0554</td></tr>
<tr><td>RTV_B</td><td colspan="2">0.0136</td><td>0.077</td><td>4.82E-03</td></tr>
<tr><td>RTV_C</td><td colspan="2">0.0375</td><td>0.77</td><td>0.05</td></tr>
<tr><td>RTV_D</td><td colspan="2">0.0414</td><td>19</td><td>1.19</td></tr>
<tr><td>RTV_E</td><td colspan="2">0.0359</td><td>77</td><td>4.82</td></tr>
<tr><td>RTV_F</td><td colspan="2">0.741</td><td>770000</td><td>48250</td></tr>
</table>

The complete kinetic outgassing database is provided by Systema/Outgassing [9], by COMOVA [10] and by ESTEC [11].

First step of the analysis is to model geometrically the complete satellite. As seen in Fig 4, the LCT, located on the top floor, is considered as a toroid geometry in order to simulate its rotational movement and taking in consideration each possible position of the Optical Surfaces (elevation and azimuth).

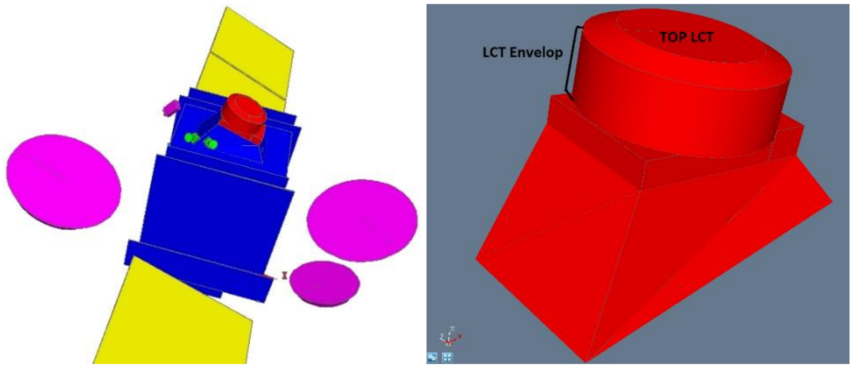

Fig. 4. EDRS-C Systema/Outgassing model

When operating, the LCT is pointing to earth. Therefore the top side of the LCT envelop models operation positions of the LCT. When moving from the parked position to the operation position, the LCT can point to different parts in space. These positions are modelled with the side part of the toroid. When parked, the LCT is linked to its support. A small gap between the LCT and the exterior is modelled.

The second step of the analysis is to identify all materials inside and outside the spacecraft that can be a threat to the LCT. In the case of EDRS-C, the internal materials that have been modelled are the cables (wrapped in Kapton) and clic-bonds (glued and in plastic) inside the main satellite cavity. In fact, as seen in Fig. 5, the main cavity is communicating with the top floor through venting holes in the structure. The LCT is located above the MLI and therefore, can be contaminated from outgassed molecules travelling through these venting holes. The external materials of EDRS-C are the MLI surrounding the structure, the CFRP structure, the silicone RTV used to glue the OSR (Optical Sun Reflectors) and the solar panels. The solar arrays rotation has been taken into account from 0˚ to 350˚ with a step of 10˚. For each rotation, a 15 years complete simulation is performed. The final deposit is an average deposit for all positions.

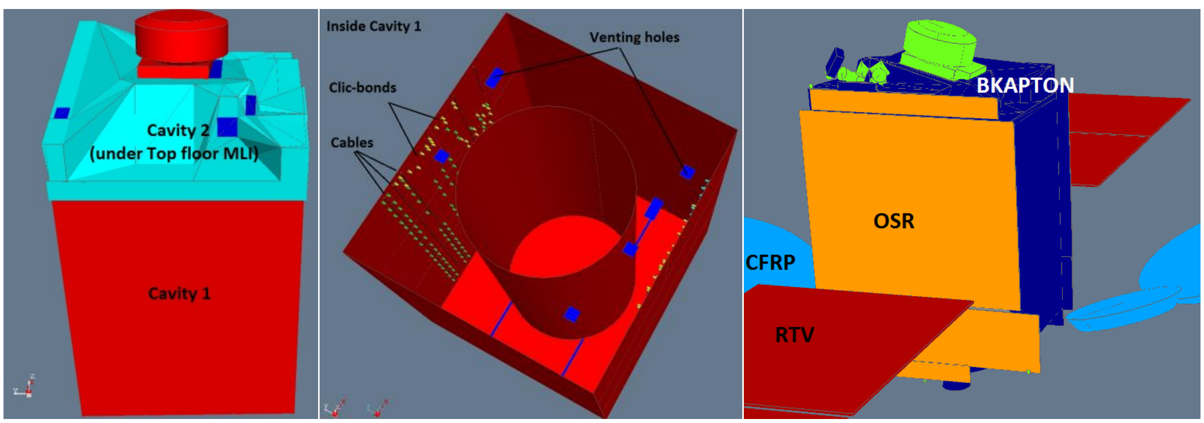

Fig. 5. EDRS-C inside and outside materials

The final step is to take into account each component temperature evolution that has been extracted from spacecraft thermal analysis. Temperatures for all seasons (summer, equinox 1, winter and equinox 2) are taken into account. The LCT temperatures are constant during whole satellite life. As the toroid envelop the LCT in each position, temperatures are linked to the location where the LCT is operating. During operations, the mirror position is the top side and operates at Hot Operation Temperatures. During travelling, the mirror position is "around" the envelop and travel at Cold Operation Temperatures. When parked, the LCT will be at survival temperatures and in the bottom position. The gap is modelled at 1K due to simulation constraints (1K is a fictive temperature in order to collect all contaminants coming from outside).

B. EDRS-C Simulation main outcome

Fig. 6 shows the impact on the LCT by species after 15 years of mission. The internal materials are not represented in the next figures because their contribution is negligible. Only heavy species are presented in the curves, light species are quickly re-emitted to the space, their contribution is also negligible. In addition, the major part of the light species will be evacuated during thermal vacuum.

When the mirror is on the top side of the LCT, it operates at high temperatures. Therefore, the species are re-emitted except for the RTV. This is due to the geometrical configuration of the spacecraft and the outgassing properties of the RTV. As seen in Fig. 4, the solar arrays have a direct view with the LCT. The residence time of the RTV is slow and, although some RTV is re-emitted, the continuous outgassing of the silicone leads to a maximum deposit at half time of the mission. When travelling, the LCT collects CFRP species from east and west antennas. The parked position collects contamination from the MLI on the top floor. In this position, the LCT is safe from outgassing from the solar arrays.

The final deposit on the LCT can be derived by taking into account mission scenario. For each position, the total duration is extracted from EDRS-C mission planning.

Table. 5. Final deposit on the LCT by mission duration

Manoeuver	Mission Duration (%)	Final deposit (ng/cm2)
LCT Operating	93	< 50
LCT Travelling	0.02	< 50
LCT parked	7	< 50
	Total	< 200

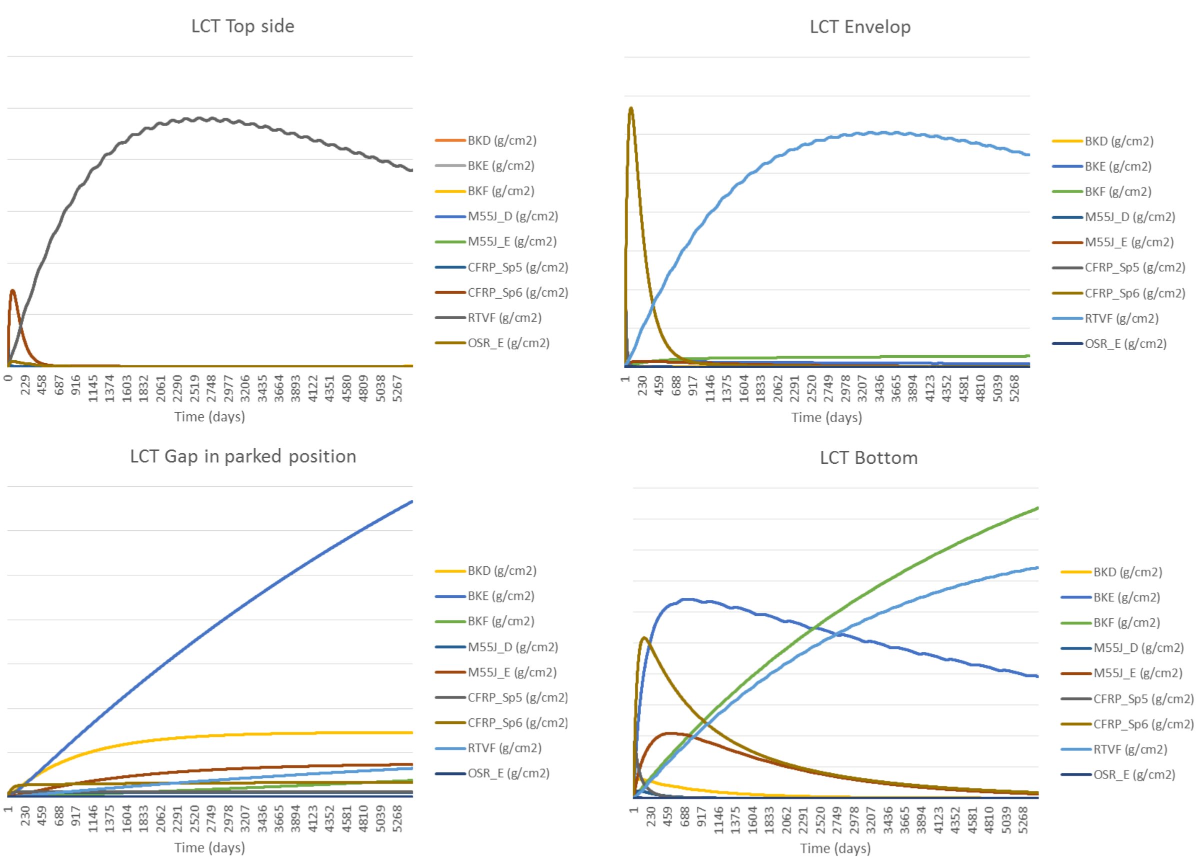

Fig. 6. Deposit by species on the LCT

V. CONCLUSION

As described in the introduction, the aim of this paper was to present the contamination control and analysis carried out in the frame of the EDRS-C mission.

Going through an overview on the On-Ground Contamination Control and In-orbit Analysis, OHB System has demonstrated the compliance to the stringent performance requirements imposed by the LCT optical surfaces at the BoL and EoL.

Identifying the major contaminants during the operative life, the In-Orbit Contamination Analysis has provided important confirmation to the satellite design and inputs to the On-Ground Contamination Control.

The On-Ground Contamination Control will be consolidated in the next months, during the AIT activities, in order to be reconciled with the predicted budget.

OHB Bremen would like to thank ESA, TESAT and Airbus Defence and Space for their contribution and support.

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