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Impact of Storage Conditions and Aging Effect on RF Breakdown and Electrical Performance in Metallic Flight Hardware

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ABSTRACT

An ageing campaign has been carried out on different metals relevant to space applications (silver, gold, aluminium and surtec modified aluminium). During this campaign of 46 months, the evolution of the TEEY has been measured at different times. Additionally, Multipactor tests have been realised at the beginning and end of the ageing process.

INTRODUCTION

It is widely assumed that the multipactor threshold of space equipment does not evolve between qualification and flight. This might not be the case for long stored equipment in non-optimal conditions. In the framework of ESA project EVEREST [1], it was clearly established that the multipactor threshold of a given critical geometry, subject to an electromagnetic field strongly depends on the Total Electron Emission Yield (TEEY) properties of the surface. Although the TEEY properties of most of the sensitive materials are well characterized, its evolution over time in controlled conditions is not yet well understood.

Nowadays, particle-in-cell software can make realistic predictions of the evolution of threshold given a certain TEEY curve. The missing piece is an understanding of the evolution of those TEEY properties.

After manufacturing, space hardware is exposed to a specific atmosphere, in that moment a layer of hydrocarbon contamination and oxide begins forming over the surface. The kinetic of the formation of this layer and its composition depends on the surface reactivity, the composition of the atmosphere, the temperature and the humidity. Therefore, the extreme-surface composition of the materials forming the RF hardware is expected to evolve during the material's life: from the manufacturing and processing (under controlled atmosphere or not) to the specific space environment (vacuum, radiations, temperature cycling, contamination,...). The consequence of these evolutions are likely significant variations of the TEEY and, hence, of the multipactor threshold.

In the framework of the ESA TRP "Impact of Storage Conditions and Aging Effect on RF Breakdown" a study was started in order to test and analyse how aging affects the TEEY properties of a group of relevant materials in the most common storage conditions for space equipment. In particular, four metals (Silver, Aluminium, Gold and Surtec) are stored in four different conditions (ambient atmosphere, ISO-8 clean room, Nitrogen atmosphere and moist atmosphere). The evolution of the TEEY and the surface chemical composition of the four materials is monitored during a storage period longer than two years. In order to correlate the TEEY to the multipactor threshold, two multipactor measures, one on the virgin samples and one at the end of the storage cycle are performed on selected samples.

I. LOGIC OF THE STUDY

In this study, the ageing process of the electronic emission of a number of different materials and stocking conditions are studied. The objective is to anticipate high power handling, in particular Multipactor, for RF material that has been stored over long periods of time prior to launch. For that, the different materials are stored in actual flight model storage facilities during an extended period of time and the SEY curve is tested along the ageing process. The storage conditions are only broken for transportation from the storage facility to the SEY testing facility (separated by approximately 10 Km). During transportation, the samples are kept in a box that is closed within the storage atmosphere in order to preserve as much as possible the storage conditions.

Due to project constraints, the ageing process has been divided in two halves. A first ageing campaign of around 20 months where the samples have been stored in the Thales Alenia Space facilities, as would be the case for flight models. And another ageing campaign of 20 to 22 months where the samples have been stored both at Thales Alenia Space and ONERA, both under similar conditions.

Four types of materials have been studied due to their interest for space applications. Each of the materials have been manufactured following the same processes utilised for flight models.

- Silver : Present in most of the high power passive equipment due to its high electric conductivity
- Aluminium : The most common material for passive flight equipment
- Gold : Highly relevant for active equipment
- Surtec : candidate substitute of alodine as a protection against ageing for aluminium

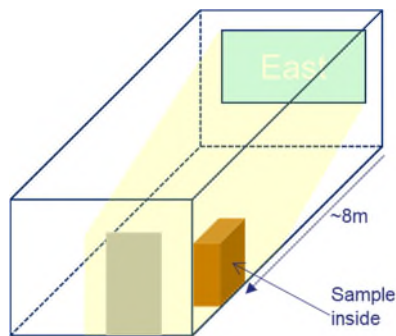
For each of the studied materials, two types of samples were realised for this project:

- Sample type #1 : only suitable for SEY measurements,
- Sample type #2 : suitable for SEY and Multipactor measurements.

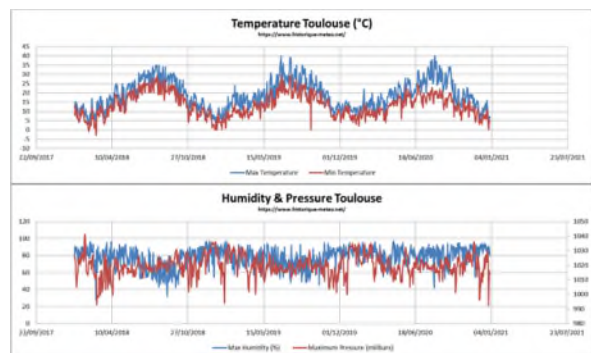
Storage Conditions

The aging process has been realised in the following storage conditions:

- Storage conditions #1: Nitrogen closet
The samples are stored in a nitrogen closet inside of a clean room. A pump constantly influxes nitrogen into the closet atmosphere and extracts air from it.
- Storage conditions #2: Clean Room ISO-8
The samples are placed in a clean room (ISO-8) similar to that of an integration room. The temperature, hygrometry and density of particles is limited in this storage condition.
- Storage conditions #3: Shelf under uncontrolled atmosphere
The shelf mimics uncontrolled conditions. The shelf is placed in a closed closet, far from any window (see Figure 1.a). The room in which is placed has morning sun exposition, and temperature controlled by A.C. and heating during working hours. The sample are kept inside of a box. The outdoor conditions feature daily thermal cycles of about 10° and long term thermal cycles of about 35°(see Figure 1.b).



a) Indoors conditions for shelf storage



b) Outdoors conditions for shelf storage

Figure 1. Storage conditions #3

Additionally, the samples under storage condition 3 also undergo the following conditions at the end of the ageing process:

- Storage conditions #4: Hot damp
These conditions are designed to mimic the ageing during qualification and the storage prior to launch. The samples underwent 14 days of 40°C at 93% HR

Campaign Logic

For each of the studied materials, the samples have been divided into three groups (one per storage conditions) and followed the ageing cycles depicted in Figure 2. Only the sample type 2 are measured both in SEY and Multipactor. The Multipactor tests are realised at the beginning of the project and at the very end.

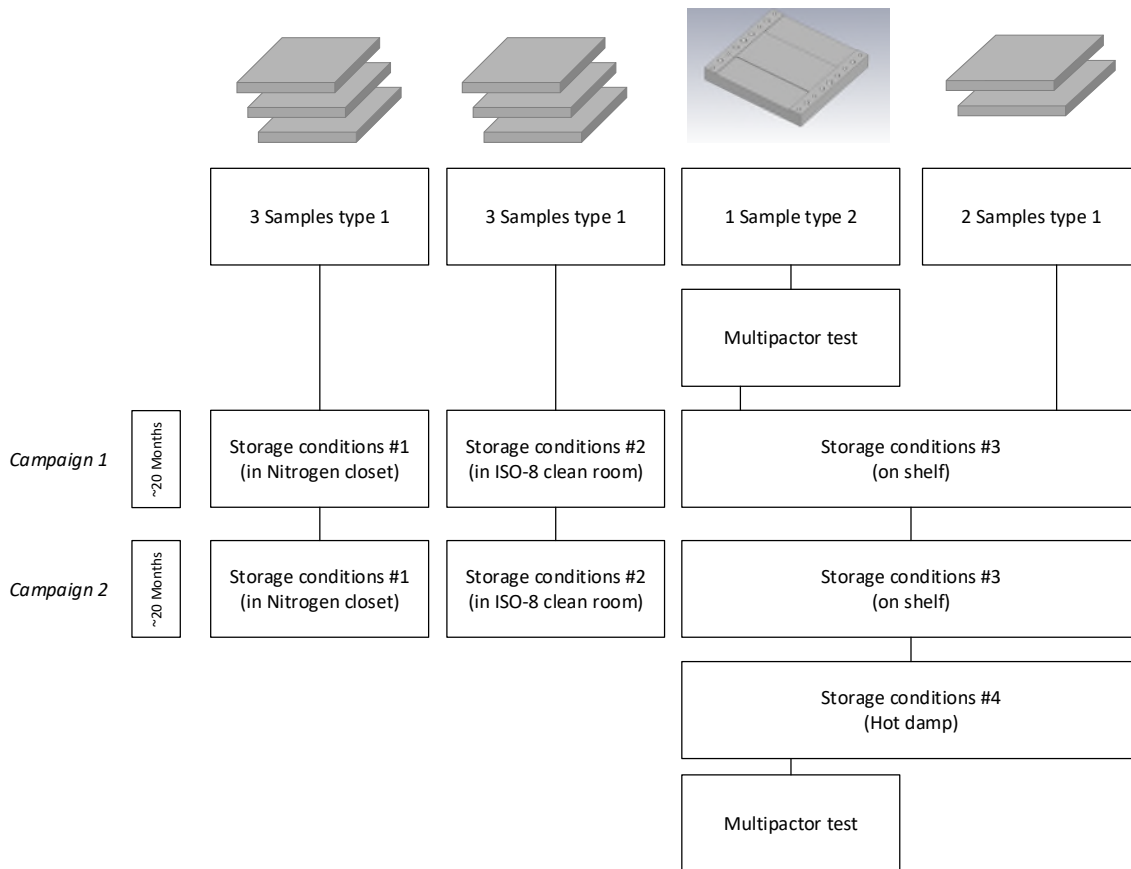


Figure 2. Ageing process for all materials

II. SAMPLES DEFINITION

Two types of samples were designed and manufactured for this project. The sample type #1 is a parallelepiped of 30mmx30mmx2mm with a flat surface designed for SEY measurements. The sample has a surface large enough to perform various measurements in the same sample and small enough for the test bench to be able to accommodate 2 samples per vacuum cycle. These samples represent the bulk of the test vehicles and will be manufactured in large quantities (32 samples in total) and will help extract an average and worst case SEY behaviour based on several curves per material.

The sample type#2 is a sample designed to be tested in SEY and Multipactor. This way a clear correlation between an SEY curve and a Multipactor test could be drawn.

The test vehicle is composed of a metallic housing, adapted to a WR229 waveguide with a deportable part in the critical gap, small enough to fit in the SEY test facilities at ONERA. This type of samples are inspired of the EVEREST [1] multipactor samples. See Figure 3 for a depiction of the test vehicle.

All of the samples and housings are manufactured in space grade aluminium and coated in silver, gold or surtec depending on the material to be tested.

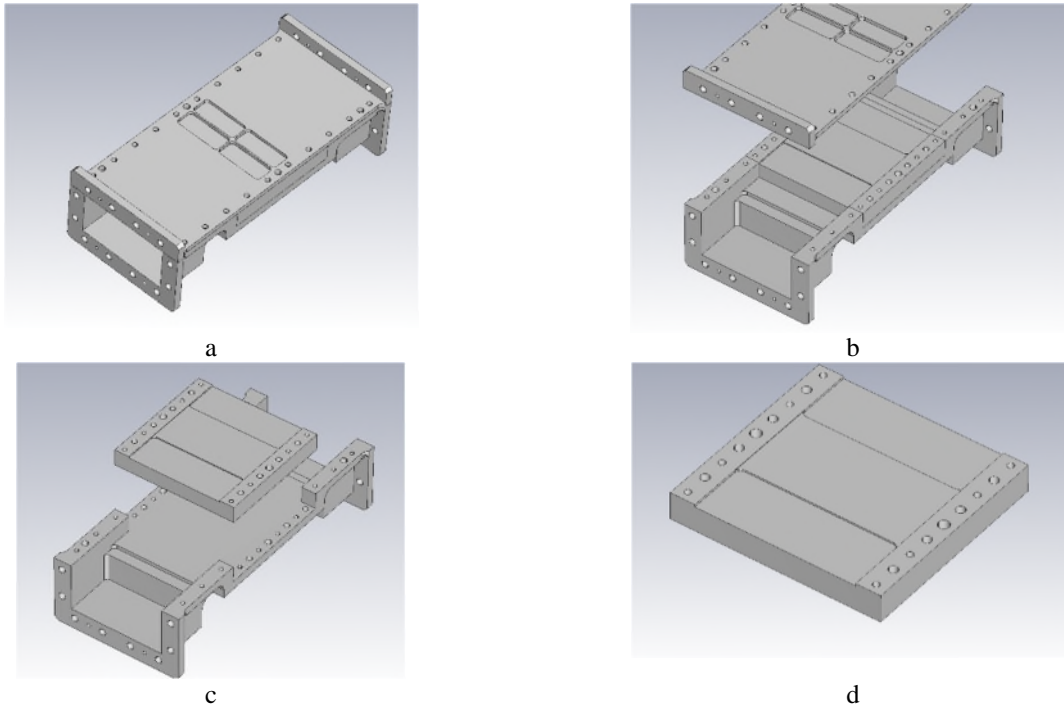


Figure 3. Type #2 test vehicle for SEY and multipactor test

III. MULTIPACTOR TEST

Silver

A special attention has been paid to the Multipactor test campaign for silver due to its relevance in the design and manufacturing of high power RF devices. Contrary to the other materials, for which only shelf storage was studied, in the case of silver, an additional ageing study for nitrogen atmosphere is realised.

Typically, flight models will undergo some sort of bake-out, either for the Multipactor test or during qualification. However, the bake-out process may clean off some of the impurities the surface of the sample under test. This could tamper with the ageing process, since for stable materials such as silver, the main contributors to the ageing process are not necessarily chemical transformations but rather a concentration of different types of pollution. Consequently, the Multipactor tests were realised without any initial bake-out.

The lack of bake-out may entail, on the other hand, a more chaotic behaviour of the Multipactor test bench. Loosely bound pollution may detach from the surface, giving way to Multipactor-like events but that are not repeatable and may not necessarily correspond to a multipactor discharge. As an example, Table 1 shows the Multipactor test for silver at T0. Although the first threshold occurs at 51dB, only at 57dB the phenomenon is repeatable.

RF(dBm)	Phase Nulling	CTCN	3rd Harmonic
43.01	RAS	RAS	RAS
46.01	RAS	RAS	RAS
49.01	RAS	RAS	RAS
50.01	RAS	RAS	RAS
51.01	RAS	RAS	events
52.01	RAS	RAS	events
53.01	RAS	RAS	events
54.01	RAS	RAS	events
55.01	RAS	RAS	events
56.01	RAS	RAS	events
57.01	events	RAS	events
56.01	RAS	RAS	RAS
56.5	events	RAS	events

Table 1. T0 multipactor test. Several 3rd Harmonic non re-peatable events detected.

Note: RAS is an acronym for No Event (Rien A Signaler)

In order to verify the effect of baking out the sample without tampering with the ageing process, a bake-out is performed on the sample after the final test and the results are compared.

The actual flow-chart of the test campaign is described in Figure 4. Two samples are aged in parallel, while one of the them is kept under nitrogen atmosphere within a clean room, the other one is aged in uncontrolled conditions for almost four years prior to a hot damp cycle of 14days. After the ageing process, both samples are tested. Finally, the uncontrolled sample is baked-out and re-tested.

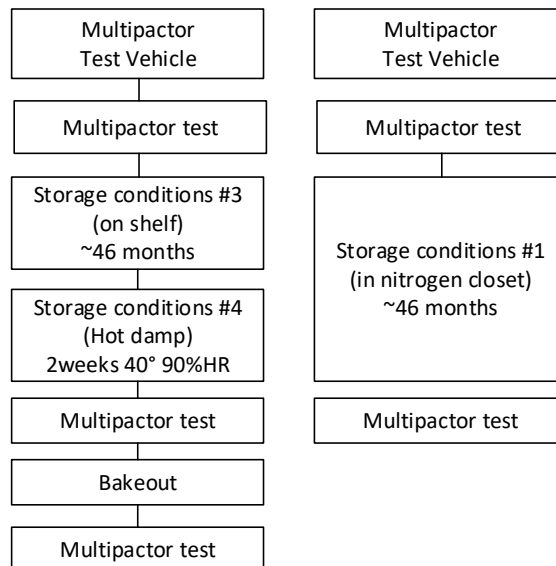
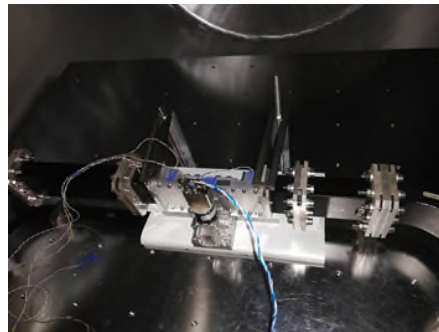


Figure 4. Flow-chart of the Silver Multipactor Test.

All the Multipactor tests are checked through three independent indirect detection methods:

- 3rd Harmonic level
- Phase Nulling
- Close to Carrier Noise

Two types of thresholds are described in this paper:

- First Event threshold: First power at which an event is recorded by at least one of the detection methods. Regardless whether the event is repeatable or not over time.
- Repeatable threshold: Threshold detected by two or three independent methods and that can be repeated over time. That is, the events disappear when the power is lowered and reappear when the threshold power is attained anew.

The results of the tests are presented in Table 2 and Table 3.

Material	First Event Threshold		
	To	To+46mo	Delta
Silver (shelf, before B-O)	56.5 dBm	49.0 dBm	-7.5dB
Silver (shelf, after B-O)	56.5 dBm	50.0 dBm	-6.5dB
Silver N2	53.0dBm	54.0dBm	+1dB

Table 2. First Event Threshold

Material	Repeatable event threshold		
	To	To+46mo	Delta
Silver (shelf, before B-O)	56.5 dBm	49.0 dBm	-7.5dB
Silver (shelf, after B-O)	56.5 dBm	54.0dBm	-2.5dB
Silver N2	53.0dBm	54.0dBm	+1dB

Table 3. Repeatable event threshold

The test results show a very stable and clear-cut threshold for the silver sample stored under nitrogen atmosphere. This threshold is well preserved over time and little variability is recorded after four years of storage. The sample that was stored on uncontrolled environment (shelf) sees a big degradation of the threshold, both the first event and repeatable threshold. This variability can be in part be attributed to the loosely bound pollution on the sample, but not entirely. The same sample, tested after bake-out shows a lower degradation of the repeatable threshold (from 6.5dB to 2.5dB of degradation of the threshold wrt T0). This spurious event may still come from the cover of the test vehicle (deported part in Figure 3b) since only a 90°C/10⁻⁷mBar bake-out was realised, as opposed to the other side of the critical gap (Figure 3d), which also underwent a stringer bake-out in the SEY test facility.

Other Metals : Aluminium, Gold, Surtec coated Aluminium

A similar campaign was realised for the other materials (Figure 2). No bake-out was performed on any of these samples and were aged only under uncontrolled conditions (storage condition #3) and hot damp (storage condition #4). There was no control test vehicle under nitrogen atmosphere.

A different variability was observed for different materials, the lowest variation corresponded to Aluminium and Surtec coating while Gold registered a large reduction in its threshold.

Material	First Events		
	To	To+46mo	Delta
Gold	61.01 dBm	52.0 dBm	-9dB
Surtec	49.01 dBm	49.0 dBm	0dB
Aluminum	47.14 dBm	50.0 dBm	-2.8dB

Material	Repeatable Threshold		
	To	To+46mo	Delta
Gold	61.01 dBm	53.0 dBm	-8dB
Surtec	54.01 dBm	51.0 dBm	-3dB
Aluminum	51.19 dBm	50.0 dBm	-1.2dB

Table 4. Thresholds for Aluminum, Gold and Surtec.

IV. FIRST AGEING CAMPAIGN (T0 to T0+20mo)

A series of metals have been aged in different stocking conditions for 21 months. The TEEY has been measured at the beginning of the campaign, mid-campaign and at the end of the campaign. The overall description of the ageing process and the campaign workflow can be found in Figure 2 and overall information of the storage conditions in paragraph I.

The different stocking conditions show an overall improvement of the TEEY. In particular a steady improvement for those samples stored in ISO-8 clean room and Nitrogen closet and a more erratic behaviour for the samples stored in an uncontrolled environment.

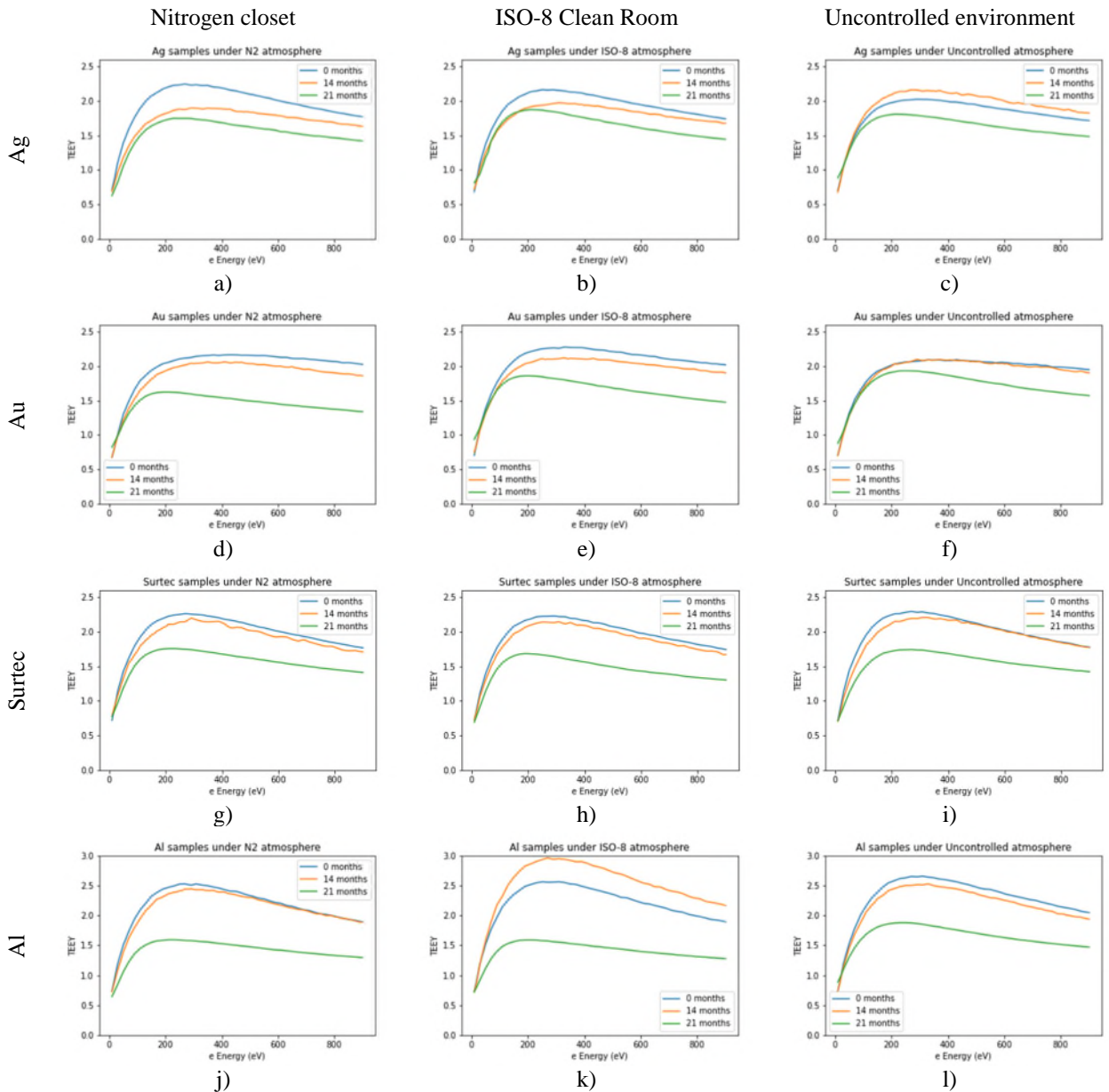


Figure 5. First Ageing Campaign TEEY: Worst case TEEY curves

Taking a closer look, a very small variation of the TEEY has been found for all materials over the first year of ageing. While the reduction in TEEY is almost consistent for all controlled environments – a special attention will be paid to aluminum in the next paragraph. Over the period of one year, gold and Surtec (and possibly aluminum) seem quite stable.

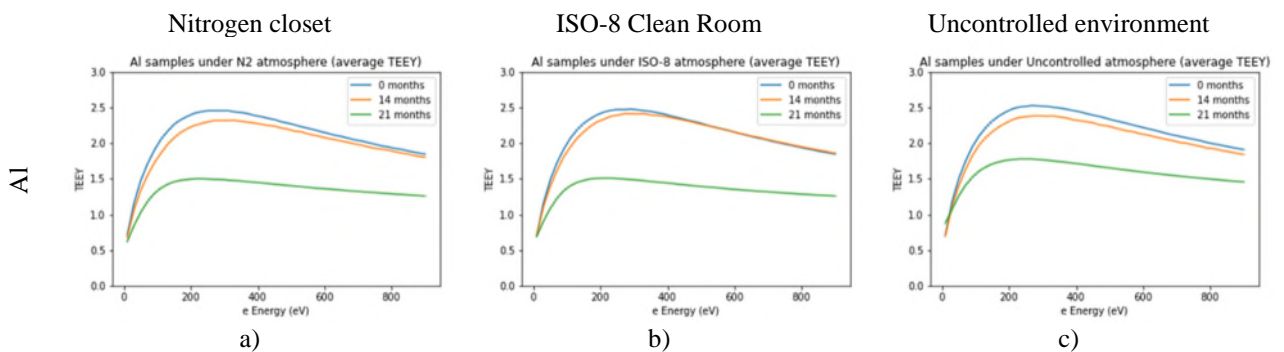


Figure 6. Average TEEY curves for aluminium

We see that although the worst case curve in the aluminum set spiked after 14 months of clean room storage (Figure 5), the average behavior did not change (Figure 6). A single curve out of 9 – 3 measurements on 3 different samples – is

responsible for this increase on the worst case behavior, this can be due to a localized variation on the surface composition. This conclusion is further supported by Figure 7 that shows clearly how only a single curve is responsible for the worst case behavior in the T+14months measurement.

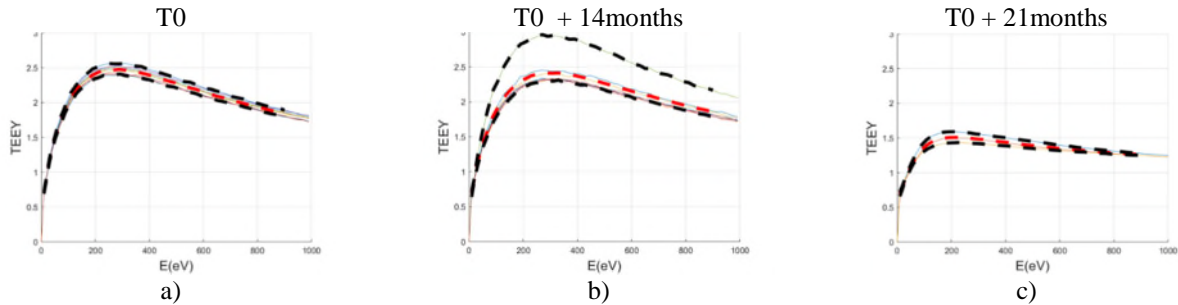


Figure 7. TEEY compilation for Aluminium in ISO-8 clean room

After 21 months of ageing, all the electronic yields are strongly reduced for all storage conditions. This may be partially explained due to the dynamic processes of contamination and decontamination. The composition of the first atomic layers is a result of dynamic completion between adsorption and desorption of atoms and molecules. It is this first atomic layer that plays the most important role in the secondary electron emission.

The main difference between the condition 3 (uncontrolled storage) and the 2 others conditions is that the main contamination source (A in the chemical equation) remains (hydrocarbon) at the contrary where with the condition 1 (clean-room) and eliminated with the condition 2 (Nitrogen). According to the literature the main hydrocarbon contamination source is due to human activity and a typical air transported contaminants varies from 0.1 to 100 μm [1,2].

When the sample is stored under Nitrogen or/and in clean room, the contamination source is reduced by one order of magnitude at the minimum (according to specifications of ISO8). As the adsorption rate is highly dependent on the flux of contaminants (number of molecules impacting the surface per second), while the desorption is mainly dependent on the concentration of the contaminants on the surface (total concentration of Oxygen and Carbon), the chemical equation results on another equilibrium situation with lower surface contamination state.

An analogy can be established with an open basin constantly filled by a faucet. De desorption rate (drainage in the analogy in Figure 8a) is determined by the surface while the adsorption rate is mainly driven by the atmosphere composition (flux of water out of the faucet in Figure 8a). The contamination level is an equilibrium that depends on both these rates.

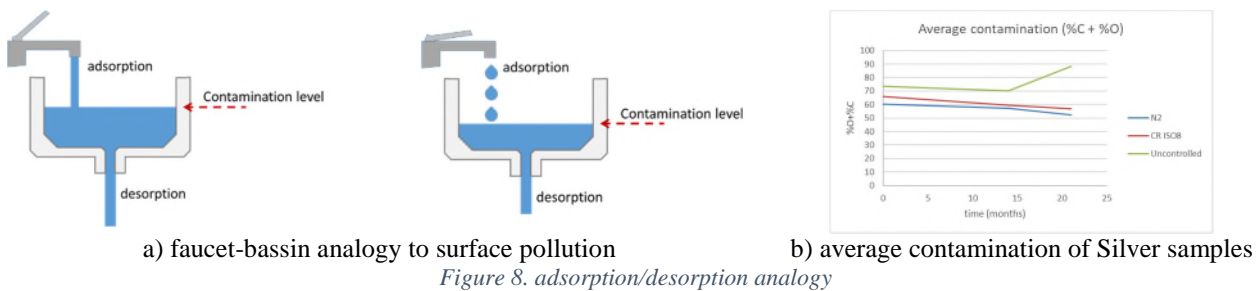


Figure 8. adsorption/desorption analogy

The contaminants (mostly Carbon and Oxygen) tend to have a higher SEY than the metal underneath. The overall TEEY is reduced as the contamination is ejected. This phenomenon has been ratified by the XPS measures of the surface composition in clean room and nitrogen atmosphere (Figure 8b). However this phenomenon cannot explain the reduction on the emission for the

V. SECOND AGEING CAMPAIGN (T0+20mo to T0+40mo)

An extension of the first ageing campaign was conducted after the first one, with measurements at T0+26months and T0+43months wrt to the initial T0. This gives a total of 3 years and a half of ageing. Figure 9 compiles a summary of some of the most relevant measures.

At the beginning of the campaign, a significant increase in the TEEY of all materials and all conditions was observed (see curve in purple of Figure 9.a and .d). This phenomenon cannot be explained as the result of ageing between T0+21 and T0+26months, especially because is present across materials and across storage conditions. As of the day of redaction of

this article, the authors are investigating the cause of this increase and more information will be shared in the oral presentation during the conference.

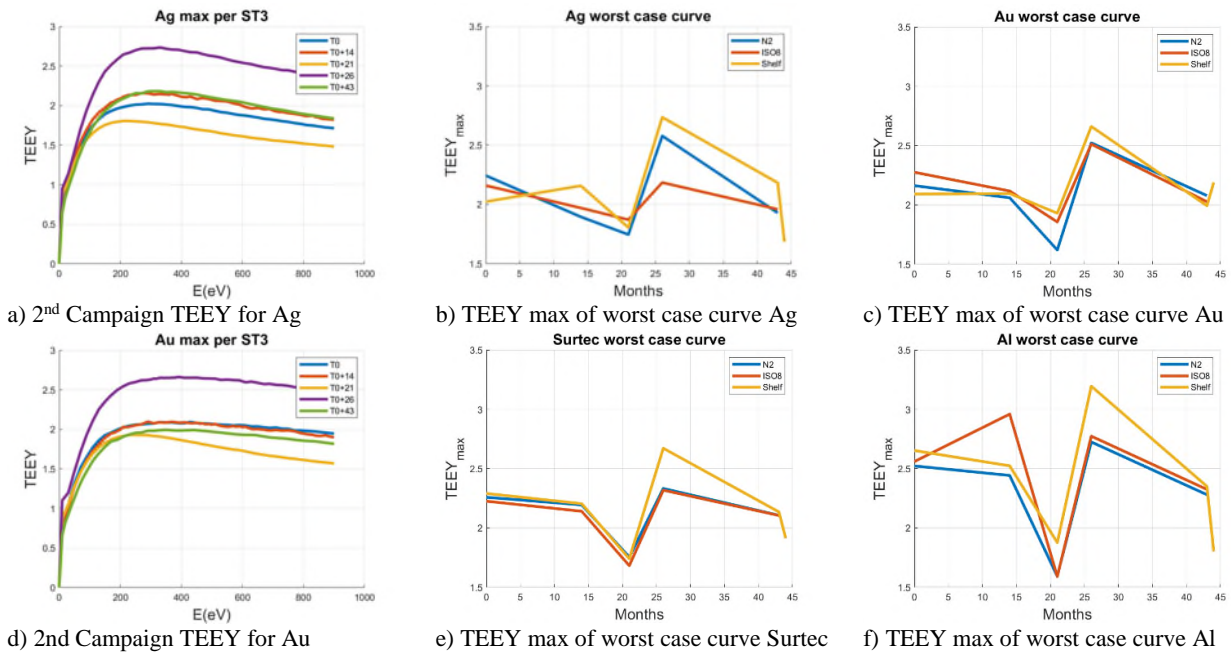


Figure 9. Max of TEEY during the first and second campaigns and TEEY for the Ag and Au samples

Although the initial rise has not been explained yet, still a phenomenon of TEEY reduction similar to campaign one can also be noticed in campaign 2. Each material and each condition drops a similar amount its maximum TEEY during a similar period as in campaign 1 (17 months versus 21 months in campaign 1).

VI. CONCLUSIONS

Two ageing campaigns have been carried out on different metallic samples. Over the first campaign a reduction of the electron emission has been observed. It has been found that for low contamination environments such as a clean rooms or nitrogen closets, the overall contamination (Oxygen and Carbon) of the metals is reduced over time, which may account for the reduction on the TEEY.

An increase in the TEEY has been observed between T0+20 months and T0+26months for all samples, this cannot be due to mere ageing and the authors are investigating the root cause. More information will be presented during the oral presentation in the conference.

In terms of Multipactor threshold, each material shows different variability over time. It can be concluded that, for long terms storage, the multipactor threshold should be stable for devices under nitrogen atmosphere. However, each material is different and some cases, like aluminium, may saturate its contamination fast and keep a rather stable threshold over time.

VII. REFERENCES

- [1] Evaluation and validation of the electromagnetic software, test facilities and test standards in Europe to predict and test RF breakdown and passive intermodulation ESTEC contract 5568/07/NL/GLC
- [2] Amodio M, Catino S, Dambruoso P R, de Gennaro G, Di Gilio A, Giungato P, Laiola E, Marzocca A, Mazzone A, Sardaro A and Tutino M 2014 Atmospheric Deposition: Sampling Procedures, Analytical Methods, and Main Recent Findings from the Scientific Literature Adv. Meteorol. 2014 e161730
- [3] T Gineste, M Belhaj, G Teyssedre, J Puech Investigation of the electron emission properties of silver: From exposed to ambient atmosphere Ag surface to ion-cleaned Ag surface Applied Surface Science 359, 398-404