System impacts of Propulsion Passivation

Clean Space days

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D Briot (Space Debris Mitigation coordinator)
S Jallade (Study manager)
S.Garces, S.Goodburn (WP managers)

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Contents of the presentation

Presentation is based on the Propulsion passivation study current results, and follows the same logic

1. Study objectives
2. SDM requirements for passivation : "deplete or make safe"
3. In orbit results for propulsion passivations
4. Current passivation performance and risk during disposal phase (overpressure, hypervelocity impacts)
5. Passivation devices solutions
6. Preliminary conclusions

Presentation for the Clean Space days is focusing more specifically on some major system issues driven by safety/reliability concerns

Study objectives and status (1/2)

Objectives of the "Propulsion Passivation" study :

⇨ provide a set of **recommendations for propulsion passivation**

a) for **running missions** (missions already designed/built, in orbit or still at ground)
- Operations to achieve the best possible passivation

b) for **new missions**
- Improved passivation with additional passivation devices : which one, which operations

Several steps:

1. analysis of propulsion SDM requirements,
2. review Propulsion Passivation strategies done in orbit on recent programs,
3. recommendations for running missions
4. passivation device trade off and recommendations for new missions
5. roadmap for developing necessary units or additional analyses

Study objectives and status (2/2)

Propulsion systems

a) LEO :
- Hydrazine (with or without membrane)
- 10 years operational lifetime
- disposal phase : 25 years

b) GEO
- Biproprellant
- 20 years operational lifetime
- Pressurant lines : a few months lifetime
- disposal phase: > 100 years

Team = Airbus Defence and Space
- Toulouse (system, lead, LEO heritage),
- Stevenage (propulsion systems),
- Lampoldshausen (propulsion units and expertise)

Study conditions
- GSP, 300k€
- Study started in 2015: to be ended in the coming months

Applicable SDM rules for Propulsion passivation

- The objective of the propulsion passivation is to ***deplete or make safe*** all remaining on-board energy at the end of its disposal phase.

- Need for high **probability of successful disposal** > 0.9 TBC
  (new absolute value, not yet applicable but under discussion at ISO/ECSS level)

- Propulsion passivation is not mandatory for LEO missions with controlled re-entries

ESA policy (IPOL2014)
It complements ECSS-U-AS-10C
It does not introduce modifications for propulsion passivation

ECSS-U-AS-10C
It complements ISO 24113
It does not introduce modifications for propulsion passivation

ISO 24113
The international standard for space debris mitigation

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“Permanently deplete or make safe” : 2 alternatives

Permanently
Deplete
or
Make safe

Passivation action shall be permanent

At least 100 years for GEO S/C

At least 25 years for LEO S/C

No energy on board

⇨ a **specific passivation device** is required (with current designs, there are some residual propellant on board)

⇨ Additional risk on the mission, mass, and complexity

“low level” of energy on board acceptable if safe

⇨No need for specific passivation device if S/C design allows to achieve this sufficient low level of energy

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Passivation device : safety and reliability issues (1/2)

☺ Complete passivation is better for SDM than partial passivation…

☹ but an additional passivation device can also kill the mission in case of failure !

worst case for debris issue = in advance failure of the passivation device that kills the S/C on its operational orbit

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Passivation device : safety and reliability issues (2/2)

Several passivation device design recommendations to minimize risks:

1st criteria = Safety : additional device shall be close to 100% safe during the nominal lifetime (up to 20 years for GEO propellantS/C)

Single failure tolerant (no SPF can activates the device)

⇨ Several protected commands to operate the device (from different ways)

Reversibility of the commands (if possible)

⇨ Feasible for electric passivation (relays), not yet feasible for fluidic passivation (mechanical rupture somewhere, whatever the device)

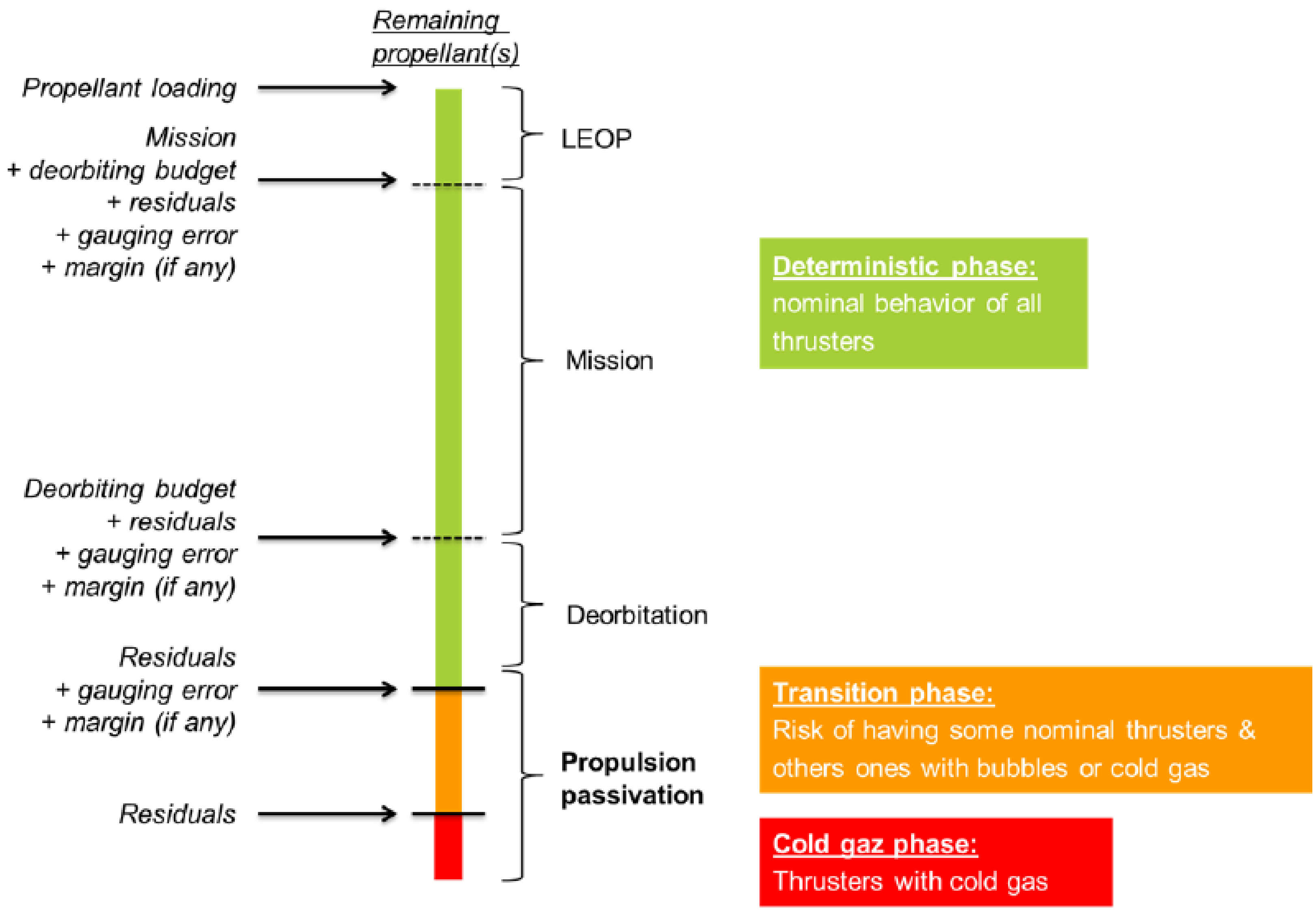
Observability : slow activation process preferred on board to allow software reaction

⇨ e.G. of slow process : SMA (shape memory alloy) actuators

2nd criteria = reliability of the passivation operations (> 0.95 TBC)

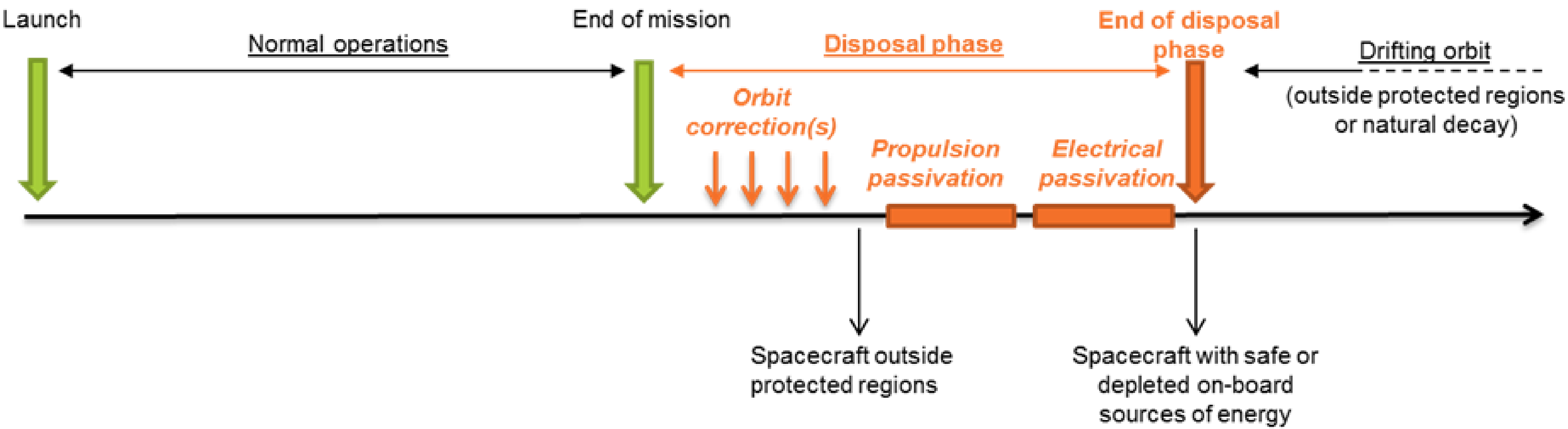
In parallel it is also useful to analyze risks with the current best achievable “partial passivation” process to see if additional device is required

Current propulsion passivation : thrusters behavior phases



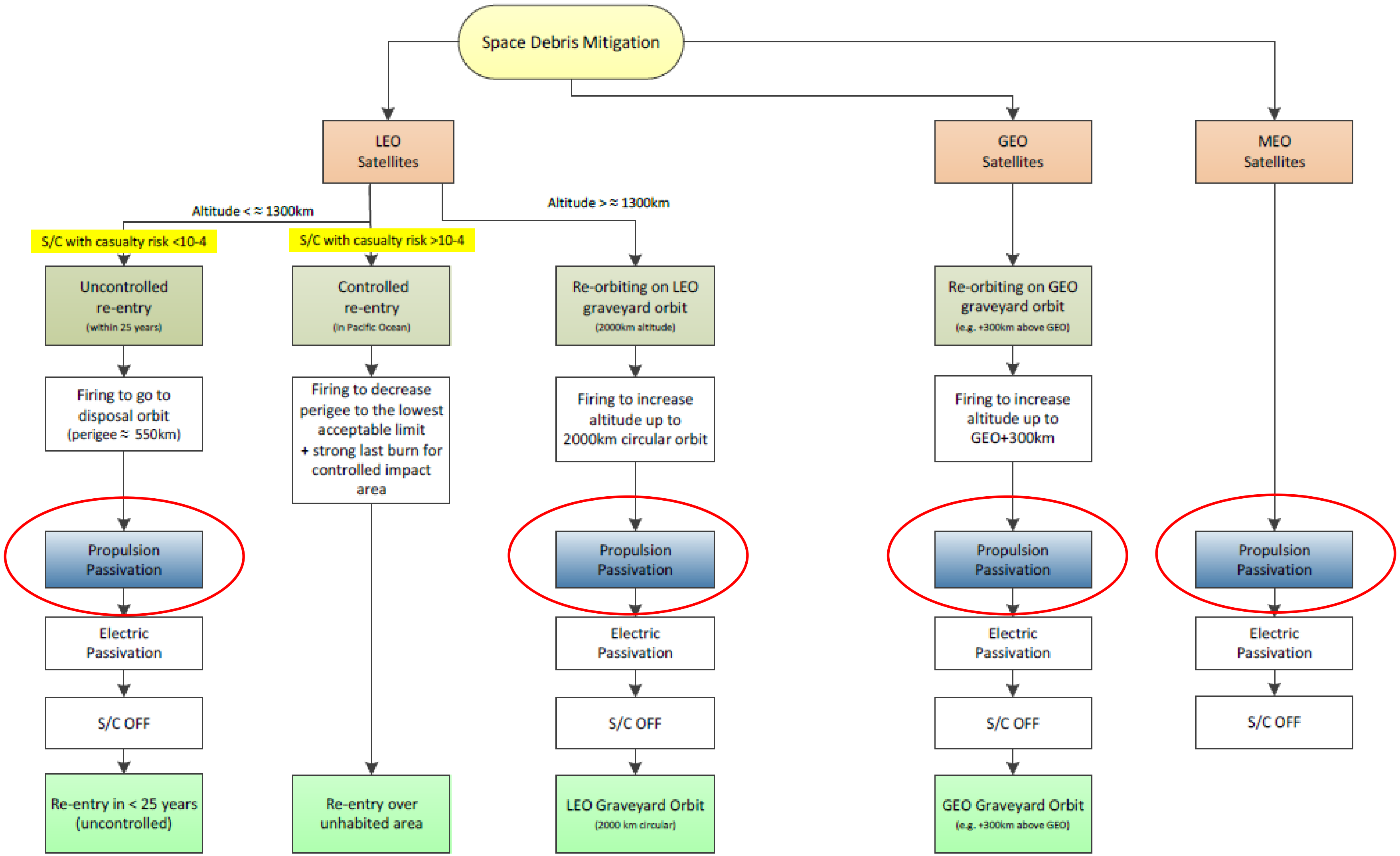
Propulsion passivation : when ?

- Propulsion passivation happens:
  - ✓ After orbit corrections to leave LEO or GEO protected zone
  - ✓ Before electrical passivation



New EOL strategies for Earth-orbiting spacecraft

Propulsion passivation required for all missions: LEO (not mandatory in case of controlled re-entry), MEO and GEO



Review of in orbit passivation results : LEO and GEO S/C (1/2)

Airbus has a long experience for in orbit propulsion passivation, that allows to assess precisely the best "partial passivation" state that can be achieved in orbit

LEO spacecraft : SPOT family (with CNES)

SPOT-METOP-ENVISAT family	Propellant before disposal	In-orbit lifetime	Passivation date	Orbit at propulsion passivation
SPOT1	60 kg	17.7 years	2003	820 / 580 km
SPOT2	60 kg	19.5 years	2009	820 / 570 km
ERS2	160 kg	16.4 years	2011	610 / 610 km
HELIOS 1A	40 kg	16.4 years	2012	Classified
SPOT 4	65 kg	16.3 years	2013	715 / 715 km
SPOT5			2015	

GEO spacecraft : several passivation done for Eurostar satellites

3 Eurostar 2000 spacecraft successfully passivated (2005-2012)

3 Eurostar 2000+ spacecraft successfully passivated (2012-2015)

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Review of in orbit passivation results : LEO and GEO S/C (2/2)

Thruster behavior

- In nearly all cases, **thrusters have been operated successfully at much lower pressure** than the nominal thruster operation range (well below 5 bars)

  At the end, mixture of propellant + gaz, without combustion, up to very low pressure values
- Final state : mainly limited by durations of operations, no real technical difficulty

  even with long open valves durations, there are still trapped propellants

Durations of EOL propulsion operations

- LEO : a few weeks (depending on the level of remaining propellant at end of mission)
- GEO : short (< 1 week in some cases)

Final level achieved : typical values

- Only a few bars in tanks (between ≈ 0 and 2 bars)
- Only a few kgs of residual

  1% of tank volume for LEO (1kg N_2H_4 for a 100liters tank)

  0.5% of tank volume for GEO (2kg MMH and 1 kg NTO for 400liters tanks)

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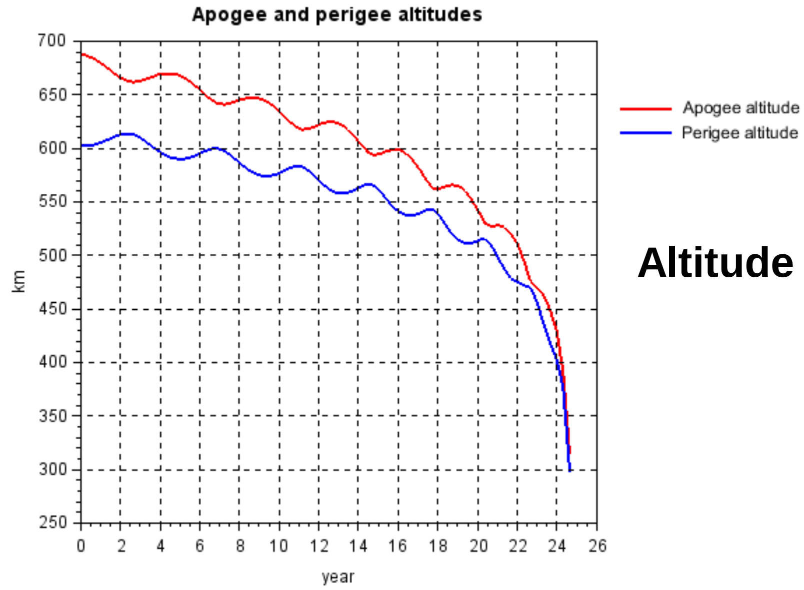
Partial passivation : environment during disposal phase for a LEO

During the 25 years disposal phase

- The altitude is decreasing
- The local solar time is varying (SSO conditions not yet fulfilled)
- The satellite attitude is uncontrolled : gravity gradient predominant at high altitude, air drag predominant at low altitude
- At low altitude ATOX will degrade kapton thermal blankets: loss of external MLIs

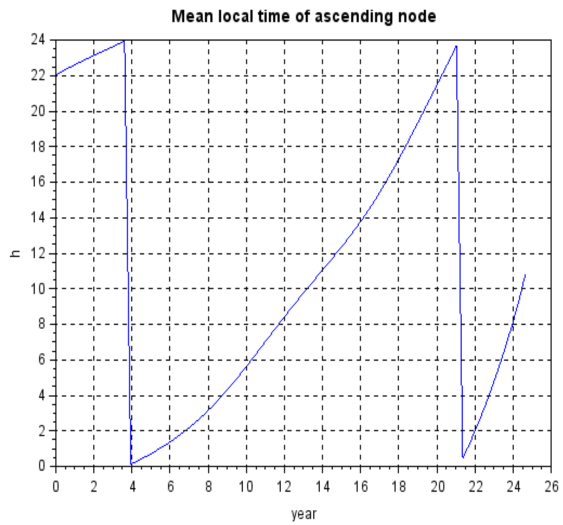


Altitude

Worst thermal case

- S/C in fixed attitude
- Propulsion module in front of sun
- No eclipse (6h-18h orbit)
- No more external MLI

☹ Tank T° can reach 100-200°C



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Partial passivation : pressure due to high temperatures on tanks

If tank T° is between 100-200°C, then propellants will **evaporate and then decompose** :
depending on propellant (N2H4, MMH, NTO), decomposition ratio is between 1.67 and 4

Temperature	Decomposition	Decomposition ratio
At ~400K [Lucien]	$3\ N_2H_4 \rightarrow 4\ NH_3 + N_2$	5/3 = 1.67

The pressure will then largely increase

- About 25 bars for typical LEO tank (1% remaining N2H4) at 100°C
- About 5 bars for typical GEO tanks at 100°C

These values are below the burst pressure : no self explosion expected (except if some fatigue effects due to ageing)

Tank explosions under hypervelocity impacts during disposal phase

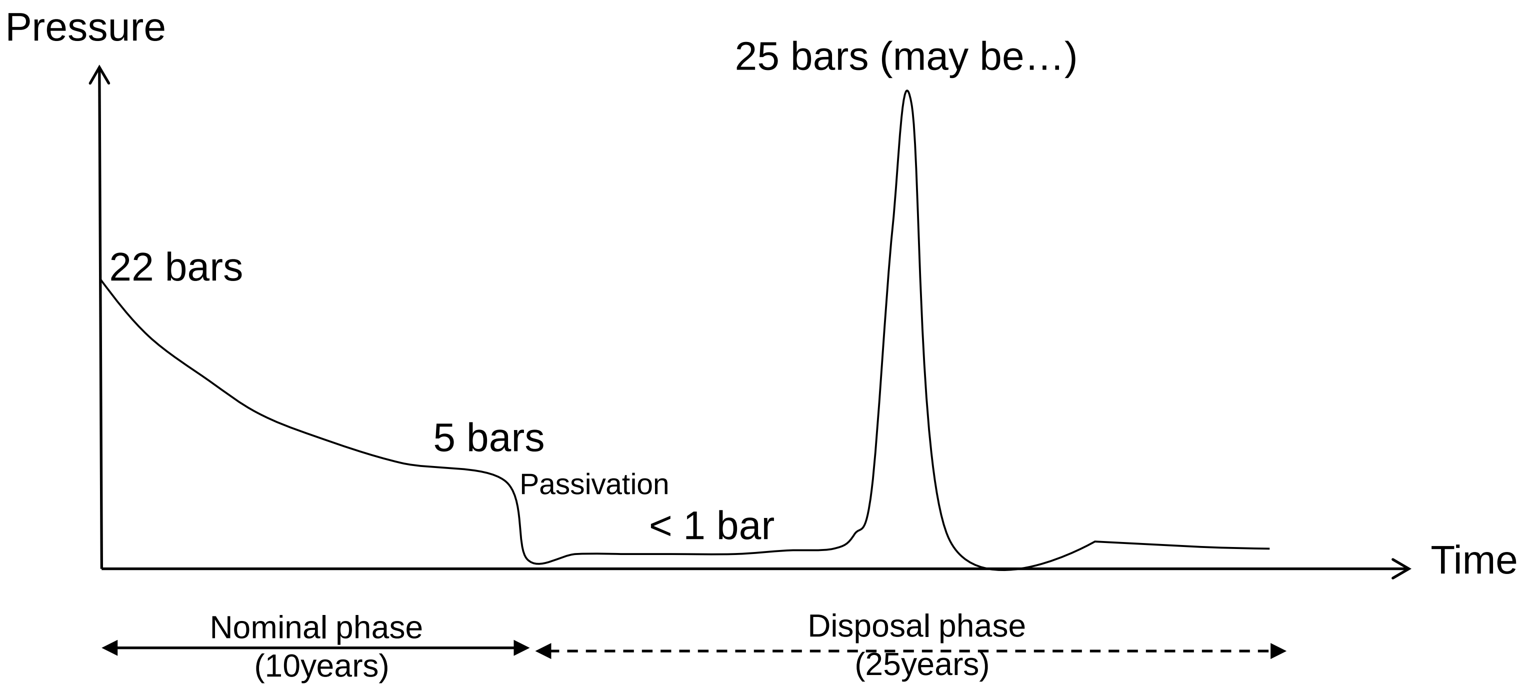
Some simple simulations done with Master 2009 model, for a AstroBus Medium satellite (Pleiades, Astroterra, S5P)

When pressure is low, number of penetrating impacts on tanks (and consequently explosion) are low : **around 1. 10-4 per year average (25 10-4 for 25 years)**

When pressure is around 25 bars, risk is higher : range 10-2 per year (TBC, under consolidation)

☞Clearly the final risk depends on the assumption of the T° on the tanks, and corresponding overpressure : to be further refined

Management of collision risks with debris during in orbit phases

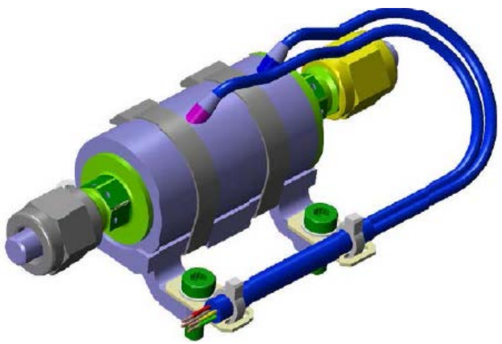


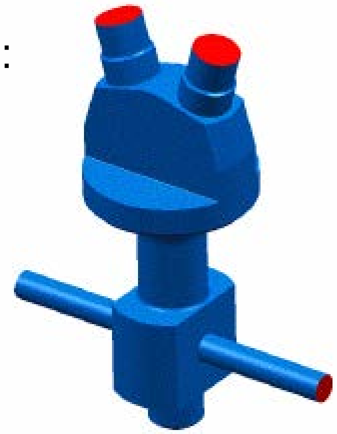
Debris size	< 1 mm (Micrometeorites, micro-debris)	1 mm < size <10 cm	> 10 cm
Nominal Phase	Protection done by design (shielding)	No protection (not feasible)	Protection done by collision avoidance
Disposal phase	Protection done by design (shielding)	No protection (not feasible)	No protection

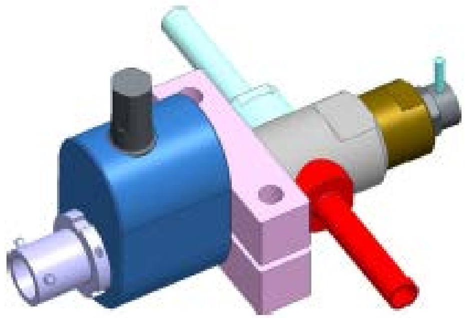
Passivation devices for complete passivation

Devices that are potentially available, at different development stages (trade off on-going):

- standard pyrotechnic valve
- extended life pyrotechnic valve
- shape memory alloy (SMA) actuator
- positive isolation valve (PIV)
- micro-perforator
- evacuation valve







Preliminary conclusions and way forward (1/2)

Passivation of the current LEO/GEO missions

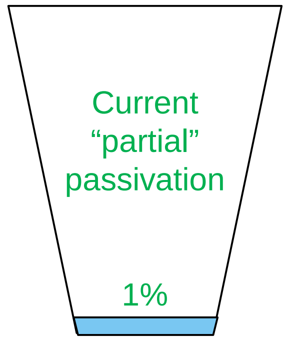
☺ practical recommendations proposed, based on the long in orbit REX in Airbus DS

Passivation devices to achieve complete passivation

☺ several possibilities can be envisaged: final choice under finalization (mass/cost/safety and reliability)

pyrovalve, SMA valve, microperforator…

☹ But lifetime of pyros systems not yet validated for 10 to 20 years



Current partial passivation (without any passivation device)

☺ Thruster behavior below 5 bars much better than expected

☺ A nearly complete passivation can be achieved (< 1% propellant, < 2 bars)

However in case of very high T° during the disposal phase, pressure in the tank can increase: up to 25 bars for typical LEO, < 10 bars for GEO

☺ No self explosion risk but ☹ risk under hypervelocity impact (TBC)

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Preliminary conclusions and way forward (2/2)

Final choice of passivation process is not simple :

☞ **is the partial passivation sufficiently safe ?**

This depends on the S/C attitude et tank T° during the disposal phase: for specific S/C families (shape, thermal hardware resistant to ATOX), the risk of explosion can be very low

☞ **Is the additional risk of a passivation device (that can kill the S/C in case of failure) sufficiently low ?**

This will depend on device designs, still under work for the necessary lifetime of 10 to 20 years

Note that comparing probabilities of the 2 feared events (S/C loss, tank explosion) is not sufficient because their gravity is very different:

⇨ discussions to be continued with SDM approval authorities

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