NASA Orbital Debris Mitigation Requirements Applied to Batteries

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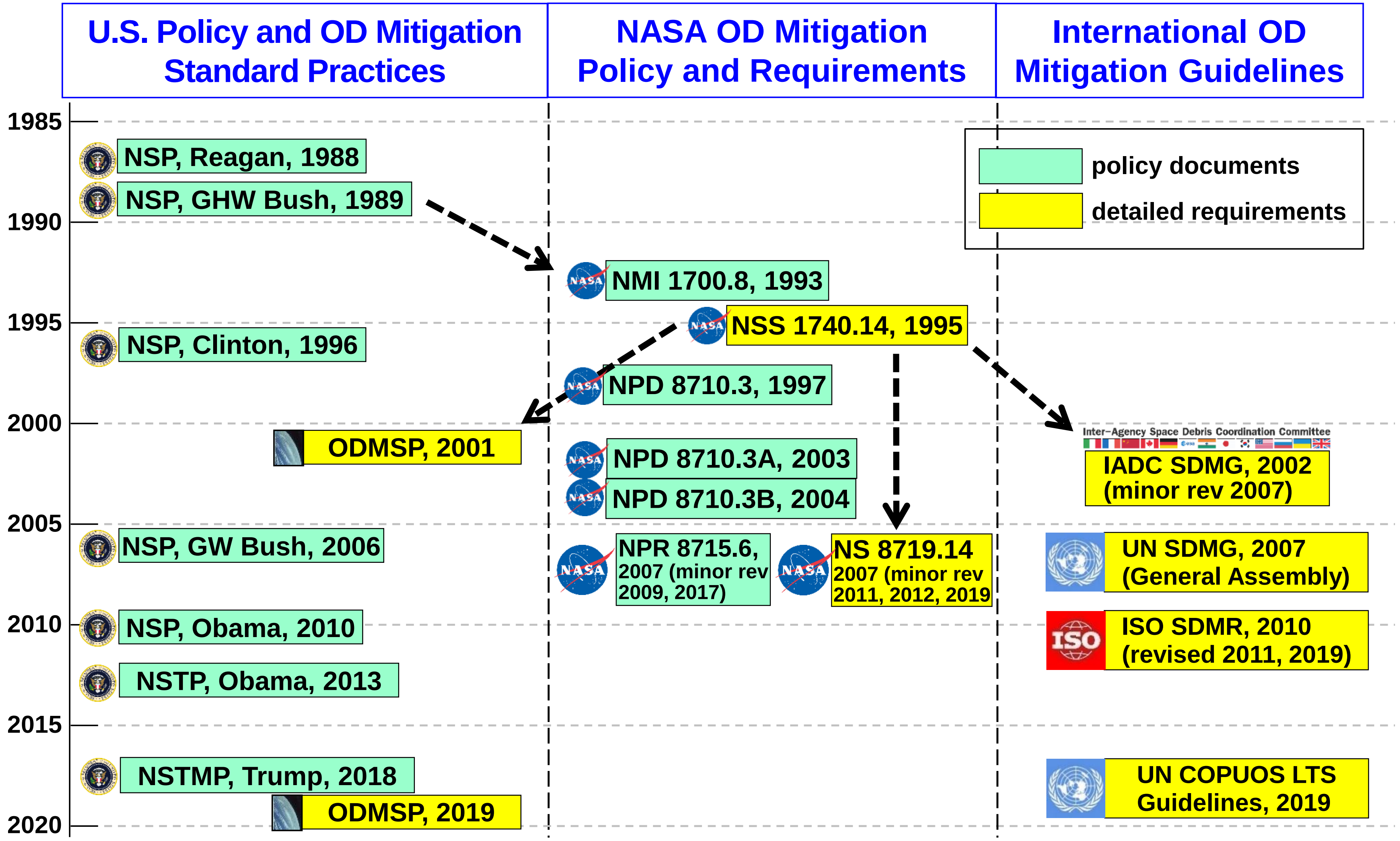
Outline

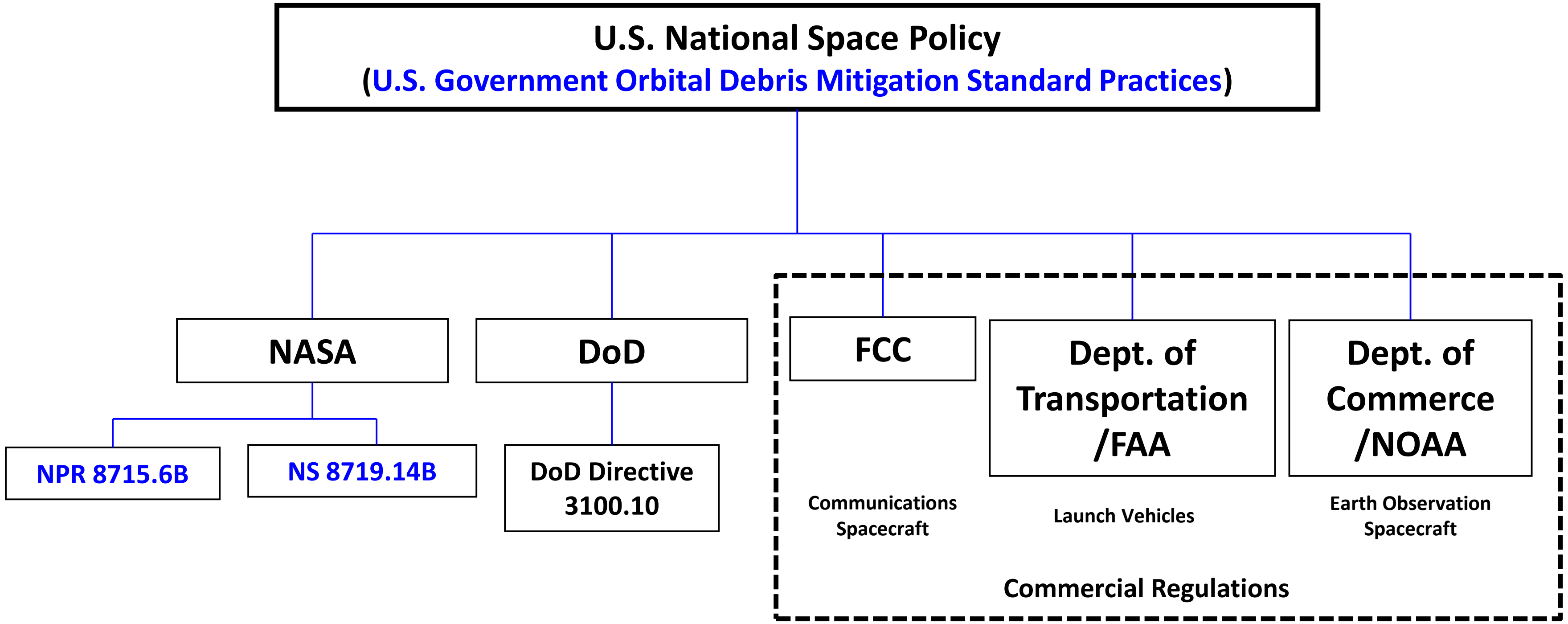
- **Orbital Debris Mitigation Policies and Guidelines**
  - NASA
  - United States
  - International community
- **Challenges for the aerospace battery community**
  - Probabilities of debris-causing events
  - Customer and regulator access to data supporting compliance

History of U.S., NASA, and International Orbital Debris Mitigation Policies and Requirements



U.S. Orbital Debris Mitigation Policies

- **All current U.S. government requirements and commercial regulations for orbital debris mitigation are derived from the 2001 U.S. Government Orbital Debris Mitigation Standard Practices, which are cited in U.S. National Space Policy in 2006 and 2010. The ODMSP was updated in December 2019.**



USG OD Mitigation Standard Practices, Objective 2: Minimizing Debris Generated by Accidental Explosions

- **Use design and procedures to avoid accidental explosions during mission operations and after disposal (passivation).**

2. MINIMIZING DEBRIS GENERATED BY ACCIDENTAL EXPLOSIONS

Programs and projects will assess and limit the probability of accidental explosion during and after completion of mission operations.

2-1. *Limiting the risk to other space systems from accidental explosions and associated orbital debris during mission operations*: In developing the design of a spacecraft or upper stage, each program should demonstrate, via **commonly accepted engineering and probability assessment methods**, that the integrated probability of debris-generating explosions for all credible failure modes of each spacecraft and upper stage (excluding small particle impacts) is less than 0.001 (1 in 1,000) during deployment and mission operations.

2-2. *Limiting the risk to other space systems from accidental explosions and associated orbital debris after completion of mission operations*: All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload. Propellant depletion burns and compressed gas releases should be designed to minimize the probability of subsequent accidental collision and to minimize the impact of a subsequent accidental explosion.

NS 8719.14B Requirements 4.4-1 & 4.4-2: Limit the Risk from Accidental Explosions

- **Two Requirements address limiting accidental explosion both during and after mission operations**
  - Quantitative, verifiable limits on design and procedures
  - Method of verification is left to the project

Accidental Explosions

Orbital debris analyses assess the probability of accidental spacecraft and launch vehicle orbital stage explosion during and after completion of deployment and mission operations.

Requirement 4.4-1: *Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon*: For each spacecraft and launch vehicle orbital stage employed for a mission (i.e., every individual free-flying structural object), the program or project shall demonstrate, **via failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses**, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle does not exceed 0.001 (excluding small particle impacts.).

Requirement 4.4-2: *Design for passivation after completion of mission operations while in orbit about Earth, or the Moon*: Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to either 1) deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or 2) control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft. The design of depletion burns and ventings should minimize the probability of accidental collision with tracked objects in space.

Assessment of Compliance with Explosion Limits

- **Quantitative threshold from Req. 4.4-1: "the integrated probability of explosion ... does not exceed 0.001"**
  - Quantitative (strong): Designer lists figures for component or subsystem reliability or probability of failure
    - Values from component manufacturers or bus supplier
    - Combine statistics to calculate explosion or failure probability
      - ➢ Probability of accidental explosion is less than (i.e., a subset of) failure probability
  - Qualitative (weak): Designer…
    - Compares the object (spacecraft or upper stage) to similar launched objects
    - States energy levels are well below safety margins
    - States compliance without specific values or available references

Assessment of Compliance with Passivation Requirement

- **From Req. 4.4-2: Deplete and disconnect energy sources and storage, *or* "control to a level" which cannot result in an event that could release orbital debris**
  - Qualitative: Designer lists the actions and hardware and software features used at end-of-mission to deplete, disconnect, and/or minimize energy generation and storage on the decommissioned spacecraft
  - Semi-quantitative: Designer may include descriptions of expected energy levels (tank pressure or cell SOC) and subsystem safety margins, especially if systems cannot be fully depleted and disconnected
  - A thorough assessment includes both of these categories

USG OD Mitigation Standard Practices, Objective 4: Postmission Disposal of Space Structures

- **Postmission disposal**
  - LEO: follow the 25-year rule and limit human casualty reentry risk to less than 1 in 10,000
  - GEO: Maneuver to a graveyard orbit ~300 km above GEO

4. POSTMISSION DISPOSAL OF SPACE STRUCTURES

Programs and projects will plan for disposal procedures for a structure (*i.e.*, launch vehicle components, upper stages, spacecraft, and other payloads) at the end of mission life to minimize impact on future space operations.

4-1. *Disposal for final mission orbits*: A spacecraft or upper stage may be disposed of by one of the following methods:

a. Direct reentry or heliocentric, Earth-escape: Maneuver to remove the structure from Earth orbit at the end of mission into (1) a reentry trajectory or (2) a heliocentric, Earth-escape orbit. These are the preferred disposal options. For direct reentry, the risk of human casualty from surviving components with impact kinetic energies greater than 15 joules should be less than 0.0001 (1 in 10,000). Design-for-demise and other measures, including reusability and targeted reentry away from landmasses, to further reduce reentry human casualty risk should be considered.

b. Atmospheric reentry: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to as short as practicable but no more than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit. The risk of human casualty from surviving components with impact kinetic energies greater than 15 joules should be less than 0.0001 (1 in 10,000).

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NS 8719.14B Requirement 4.7-1: Limit the Risk of Human Casualty from Reentering Debris

- **Batteries are not usually predicted to survive reentry…except when they are**
  - "Design for demise" considers reentry shielding of components (e.g., cells) by enclosures, MMOD impact shields, and bus interior locations
  - Releasing many small cells at low altitude is worse than retaining them in a single, larger container

Debris Surviving Atmospheric Reentry

NASA space programs and projects that use atmospheric reentry as a means of disposal for space structures need to limit the amount of debris that can survive reentry and pose a threat to people on the surface of the Earth. This area applies to full spacecraft as well as jettisoned components.
[The Requirement] applies to all spacecraft and launch vehicles returning to the surface of the Earth from an altitude of greater than 130 km.

Requirement 4.7-1. *Limit the risk of human casualty*: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000).
b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.
c. For controlled reentries, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000).

Assessment of Compliance with Casualty Limits

- **Aerothermodynamic modeling of spacecraft and upper stages**
  - NASA provides the Debris Assessment Software (DAS) tool
    - Free and publicly available (upon registration)
      - https://www.orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html
    - User inputs data for all components, including nested
  - If necessary, NASA projects may request a higher-fidelity assessment using the Object Reentry Survival Analysis Tool (ORSAT)
    - Allows specification of additional parameters
    - Upon approval, ORSAT assessment is available to commercial projects through Space Act Agreement
    - https://www.orbitaldebris.jsc.nasa.gov/reentry/

Improving Orbital Debris Assessment

- **How to increase rigor of debris assessment reports?**
  - Ask a space battery expert!
  - Educate the community about orbital debris mitigation requirements
  - Develop a standardized process
    - Encourage projects to use "*failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses*" when assessing to numerical thresholds
    - Provide quotable (i.e., available to support evaluation) references for…
      - ➢ Component numerical reliability/failure rates
      - ➢ Relevant certifications (e.g., human spaceflight certified batteries) when relying on similarity

Improving Orbital Debris Assessment

- **Perform realistic battery failure and hypervelocity impact tests**
  - How do vacuum and free-fall conditions affect the outcome?
    - Most (?) non-HVI tests in the literature were performed under bench-top conditions
  - Are there in-production cell/battery types that are inherently safe to meet the quantitative threshold?
    - Both operations and disposal
    - Shown by modeling and experimental evidence
- **Move vehicle designers from “take our word for it” to “here is the evidence”**

Think “Orbital Debris Mitigation”

https://www.orbitaldebris.jsc.nasa.gov/