Internal Radio-frequency Instrumentation System (IRIS) Overview

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Raymond Wagner, Ph.D. (JSC EV8)
raymond.s.wagner@nasa.gov

Background

- **IRIS development arose from an Orion EM-2 Developmental Flight Instrumentation (DFI) need**

- **EFT-1 DFI:**
  - ~60% of EFT-1 DFI mass due to wiring

- **Wireless DFI effort:**
  - implement and characterize the performance of a system to service low-data-rate (10Hz) thermocouple (TC) sensors w.r.t.
    - battery life
    - system mass

Wireless DFI System Requirements

Wireless DFI sensors must be…

- **completely wireless**
  - data acquisition (DAQ) and communication powered by a battery or harvested energy
- **capable of operating independently for years**
  - switched on at time of installation
  - hibernate until required for mission
- **capable of being woken instantly**
- **extremely low mass**
  - large power sources cannot be tolerated

… which eliminates traditional “active” wireless solutions like ZigBee, Bluetooth, Wi-Fi.

RFID for Inventory Management

Commercial Radio Frequency Identification (RFID) standards typically allow tags to report unique IDs to an interrogator:

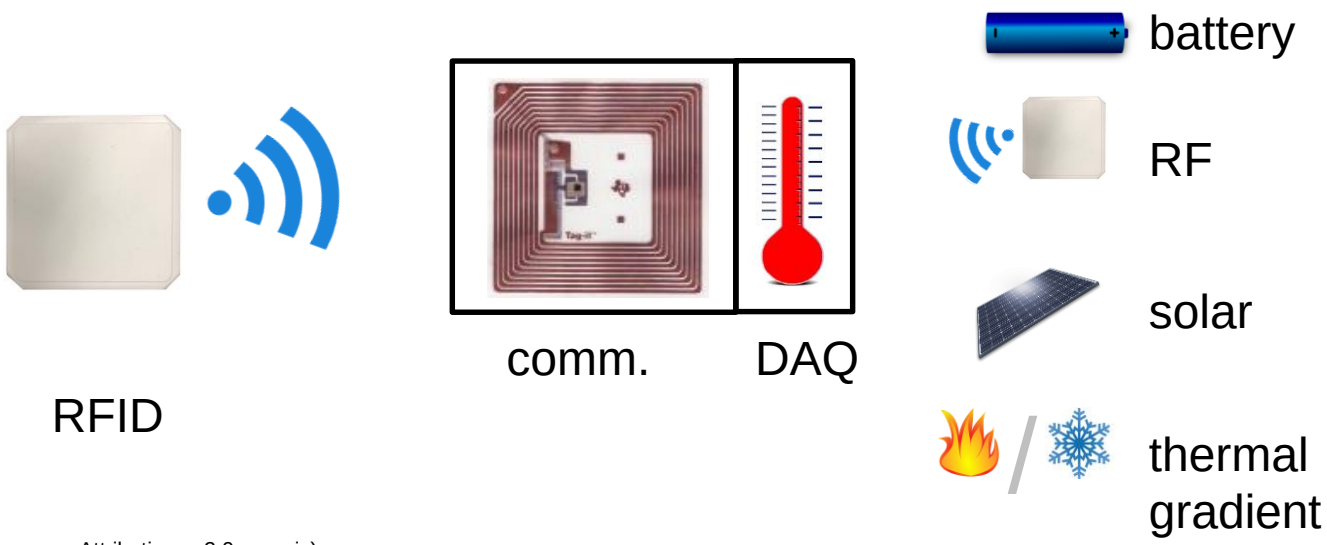
RFID for Sensing

But these same standards can transport sensor data as well:

RFID Sensing Architecture

- communication power provided by interrogator, "for free" from sensor's perspective

- data acquisition (DAQ) power can come from several sources:
  - stored power (e.g., batteries)
  - harvested power (e.g., RFID, solar, thermal,…)



Technology Study Metrics

Using RFID to stream DFI data is a novel approach. To assess the feasibility, we must:

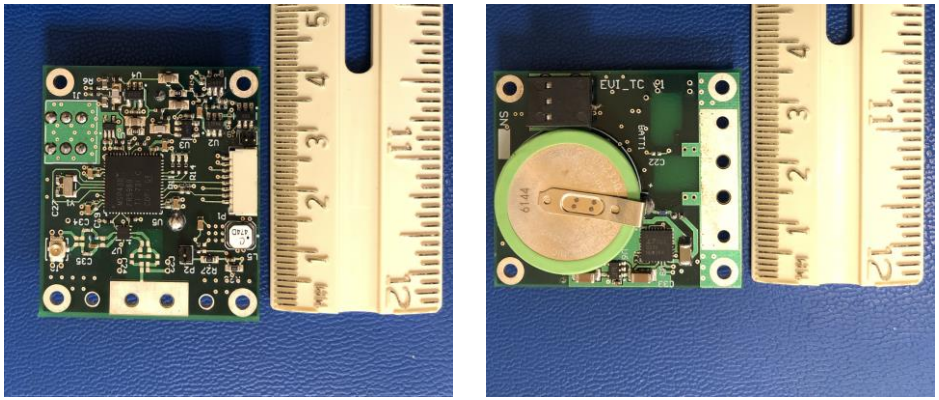
- **design extremely low-power sensor front-end**
- **select candidate RFID serial-interface integrated circuits (ICs)**
- **build prototype hardware and assess:**
  - system mass
    - tags, tag antennas
    - interrogator, interrogator antenna
  - sensor tag power requirements
  - achievable data rate
    - processor-to-tag interface
    - tag-to-reader interface
  - scalability
    - tags per interrogator
  - RF coverage

IRIS Thermocouple Tags

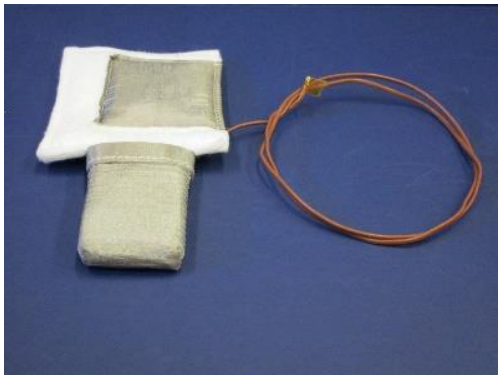
- **prototype TC tag (ODFI TC v. 1)**
  - 10.5 g.
    - 0.02 lbs.
  - 3.5 cm. x 4 cm.
    - 1.4 in. X 1.6 in.
  - BR2330A battery

- **e-textile (fabric) antenna**
  - direct textile mount
  - 11 g.
    - 0.02 lbs.
  - 10 cm. x 8.5 cm.
    - 3.9 in. x 3.3 in.

- **housing concepts:**
  - rigid housing + textile antenna
  - textile housing/antenna (pictured)
    - mass: 34.5 g. (inc. TC wire)
      - 0.08 lbs.



Orion DFI TC tag



textile antenna +
tag housing

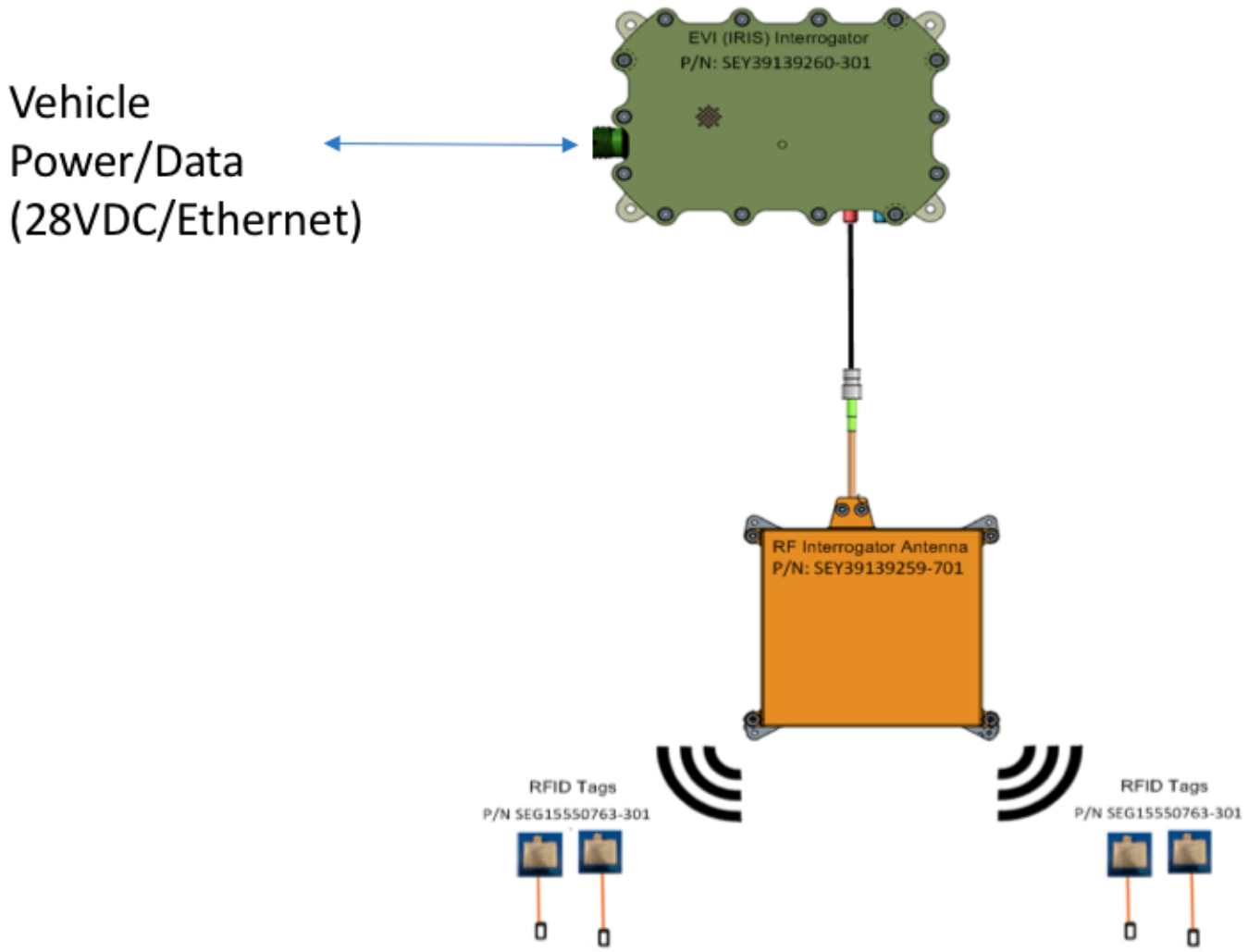
IRIS Interrogator

- **architecture:**
  - leverages Reduction RFID-Enabled Autonomous Logistics Management (REALM) Embedded RFID (EmbeR) interrogator
  - ThingMagic interrogator module
  - Gumstix single-board Linux processor
  - supports up to 4 antennas
- **mass:**
  - 473 g.
    - 1.04 lbs.
- **size:**
  - 15.5 cm x 11 cm. x 4.5 cm.
    - 6.1 in. x 4.3 in. x 1.8 in.
- **power dissipation:**
  - 0.43A at 28 VDC (~ 12W)

Interrogator Antenna

- **REALM-1 antenna**
  - low-mass 900 MHz RFID antenna
  - custom designed for ISS inventory management work
  - harvests most of mass reductions through housing re-design
- **mass:**
  - 377 g.
    - 0.83 lbs.

System Diagram



Tag Power Consumption Analysis

- **sensor tag programmed in two modes:**
  - hibernate until commanded to active mode
  - sample at 10 Hz and write to tag memory every 15s

- **currents measured:**
  - ~3.1 µA hibernation current (2.7 V)
  - ~47.5 uA active current (2.7 V)

- **battery life calculated:**
  - BR2330A (255 mAh):
    - hibernate: **9.4 years**
    - active: **223 days**

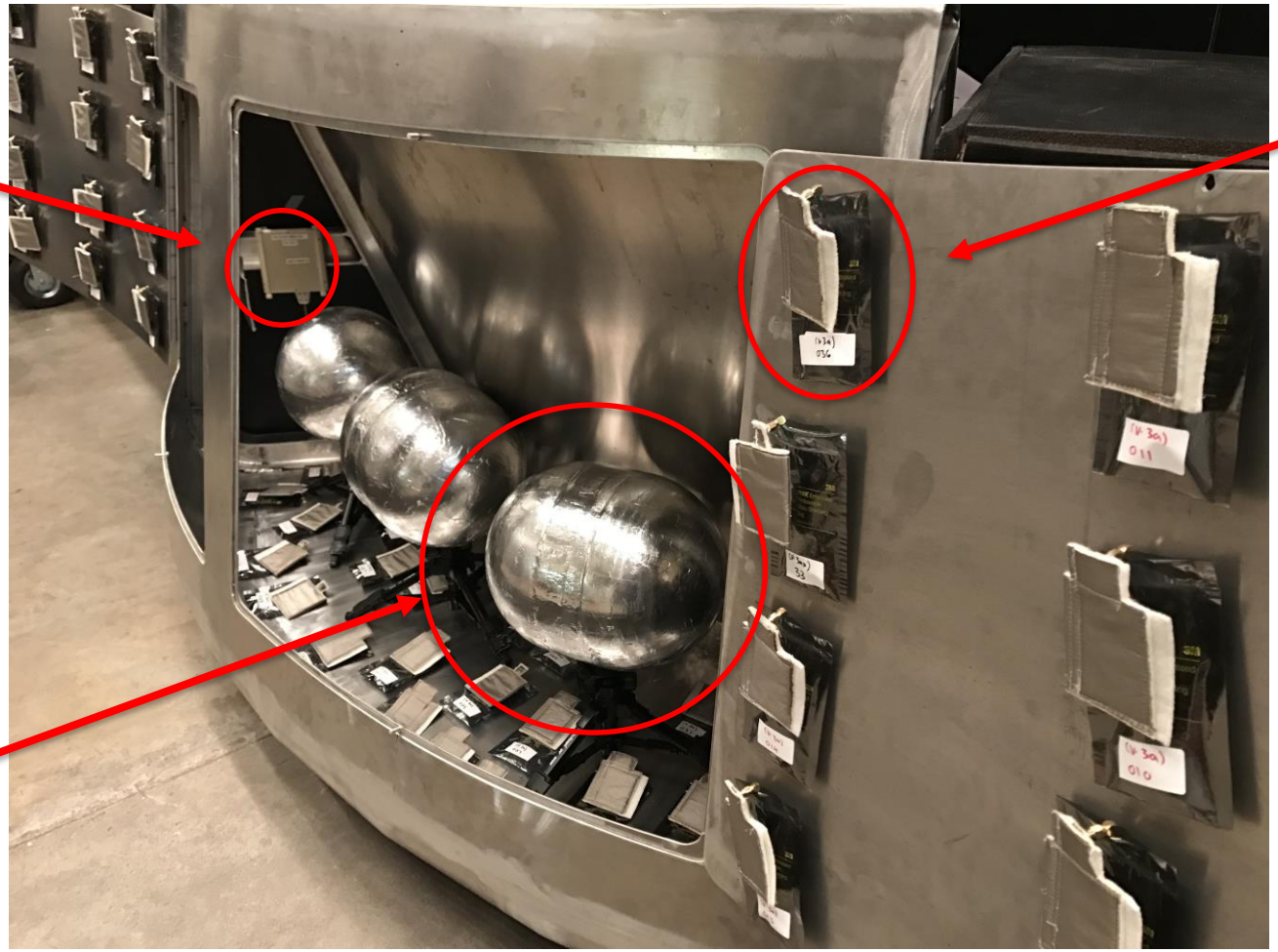
Scaling/Throughput Test Environment

- **Orion aft-bay sector mockup:**
  - derived from Orion CAD
  - populated with sensors and representative obstructions
    - **50 tags**
    - **2 “propellant” tanks**
    - **1 “coolant” tank**

exterior

interior (populated)

Scaling/Throughput Test Environment



Data Rate, Tag Population Analysis

- **Average error rate measured over 100 hours of experiments:**
  - 0.00% average packet loss observed
    - excludes progressive hardware failure in 1 tag as outlier
    - results verified over second 100-hr set (inc. similar HW failure)
    - work to characterize HW issues ongoing

- **Average interrogator-to-tag interface characterized to guide scaling estimates**
  - measured for 50 sensor tags
  - theoretically allows for ~480 10Hz tags/reader
    - retry overhead ~0.00% so should not impact limit
  - scales gracefully as tags added
  - should support in excess of 100 tags per interrogator (conservatively), provided:
    - processing burden does not become too great as tag population scales
    - all tag locations have adequate RF coverage from interrogator

Computational Electromagnetics (CEM) Coverage Analysis

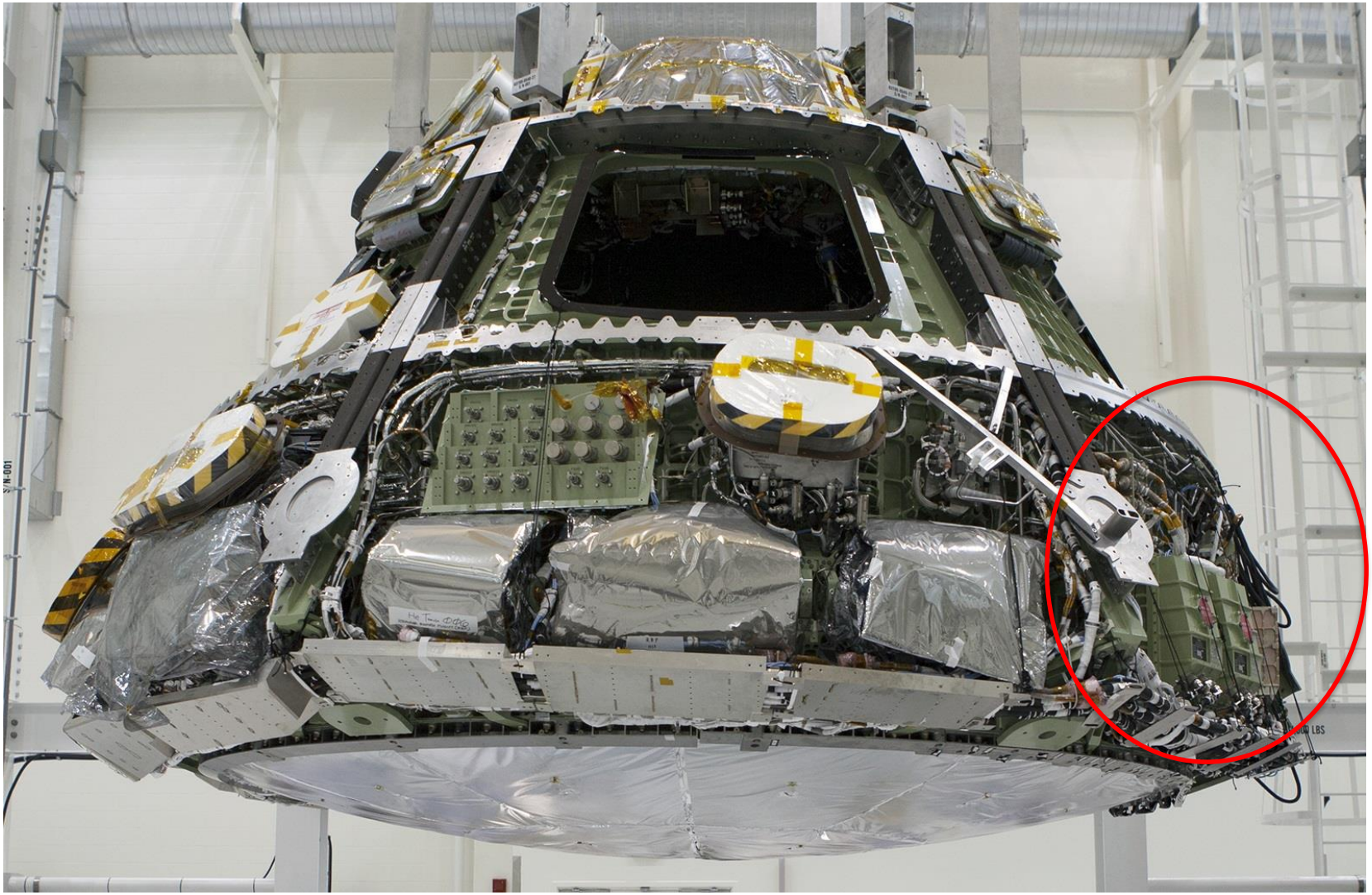
- **initial assessments conducted on EFT-1 vehicle to establish feasibility of coverage**
  - used commercial RFID interrogators/tags
  - required approximation of missing backshell/heatshield

- **CEM analysis initiated to assess coverage in operational environment**
  - Orion CAD used to build CEM models
  - Maxwell's equations solved on model assuming:
    - tag/interrogator antenna positions
    - tag/interrogator sensitivities
    - interrogator power level

Orion EFT-1 vehicle

image source: nasa.gov

Aft Bay Sector D: “least cluttered”



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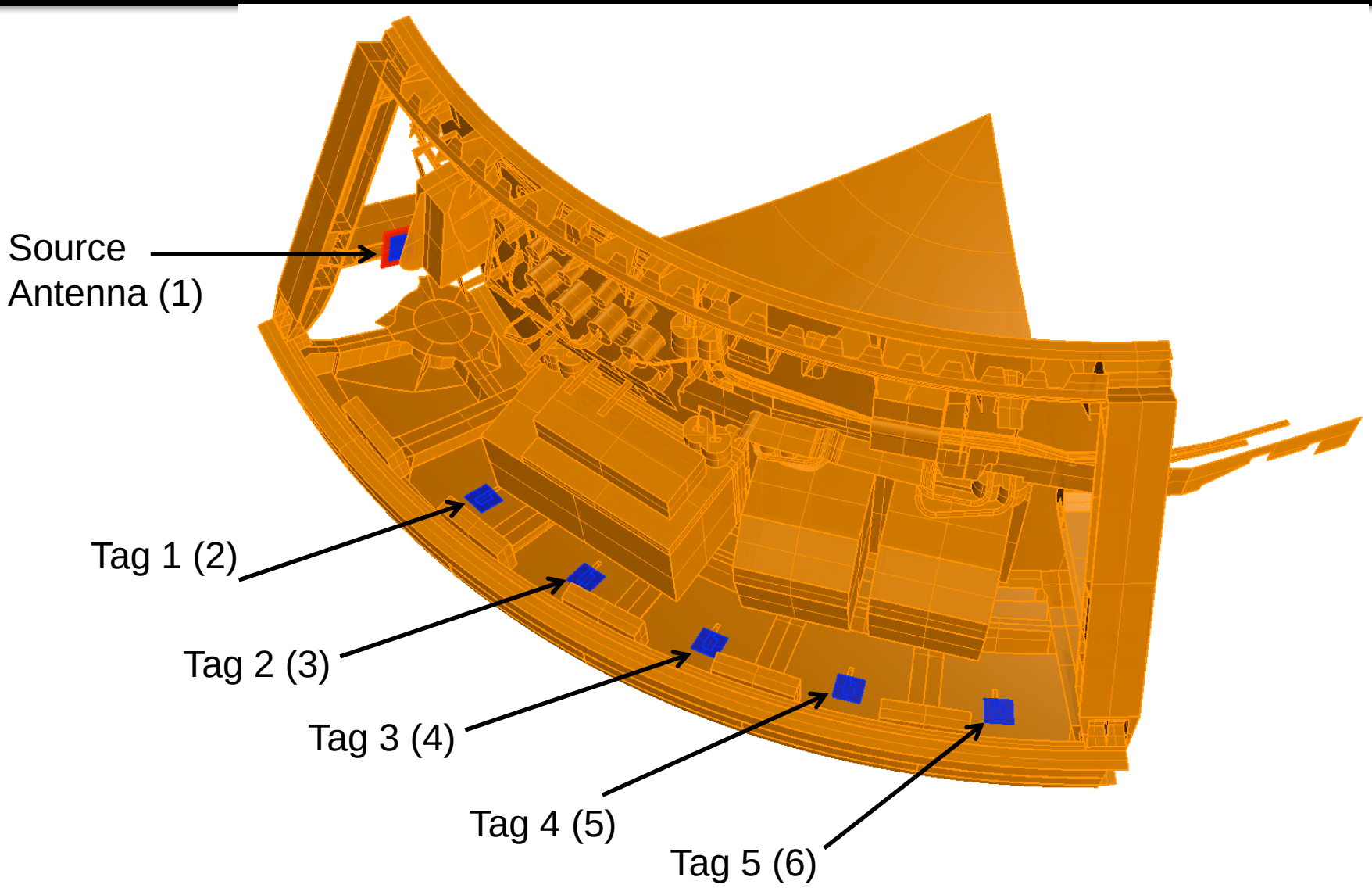
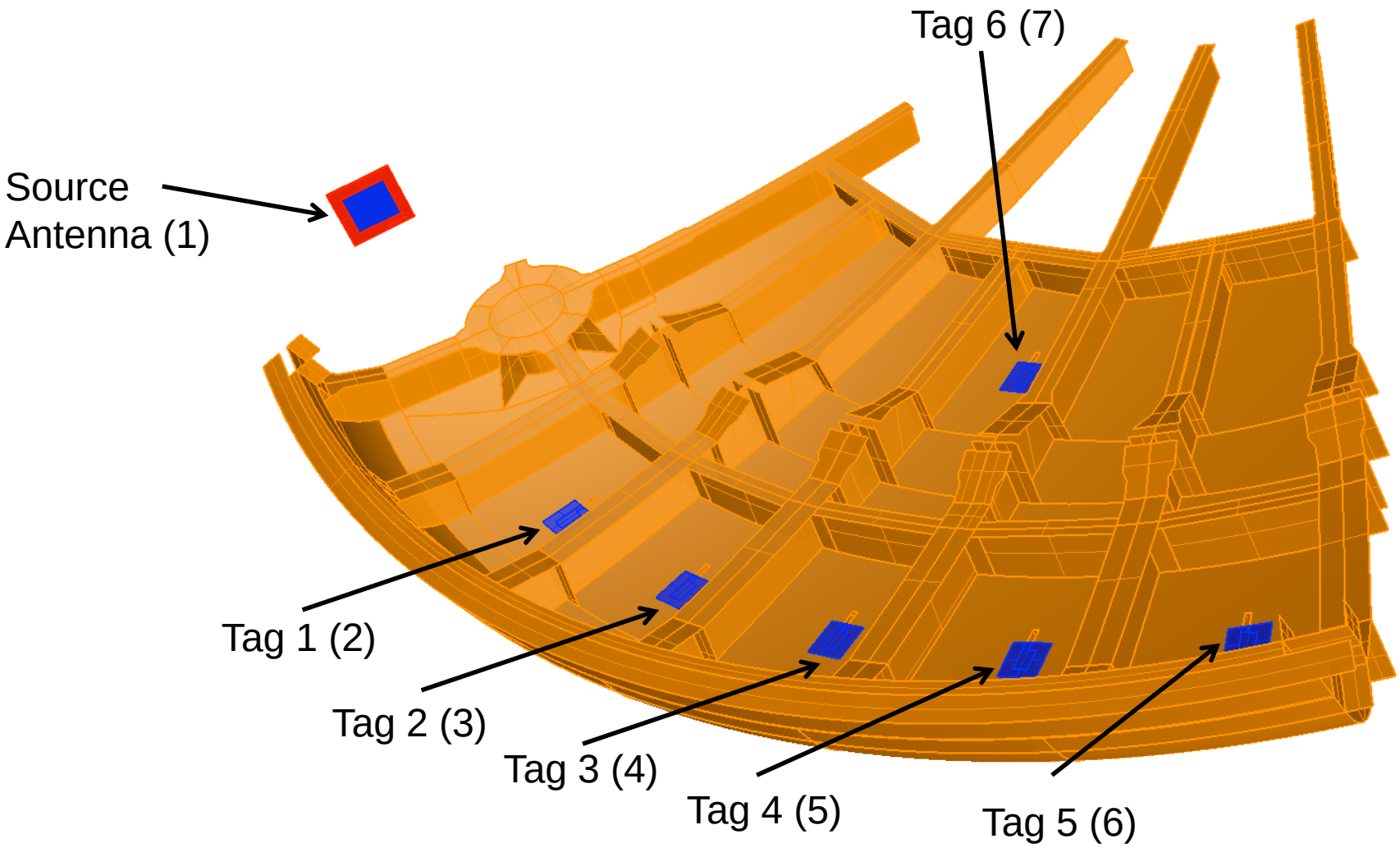
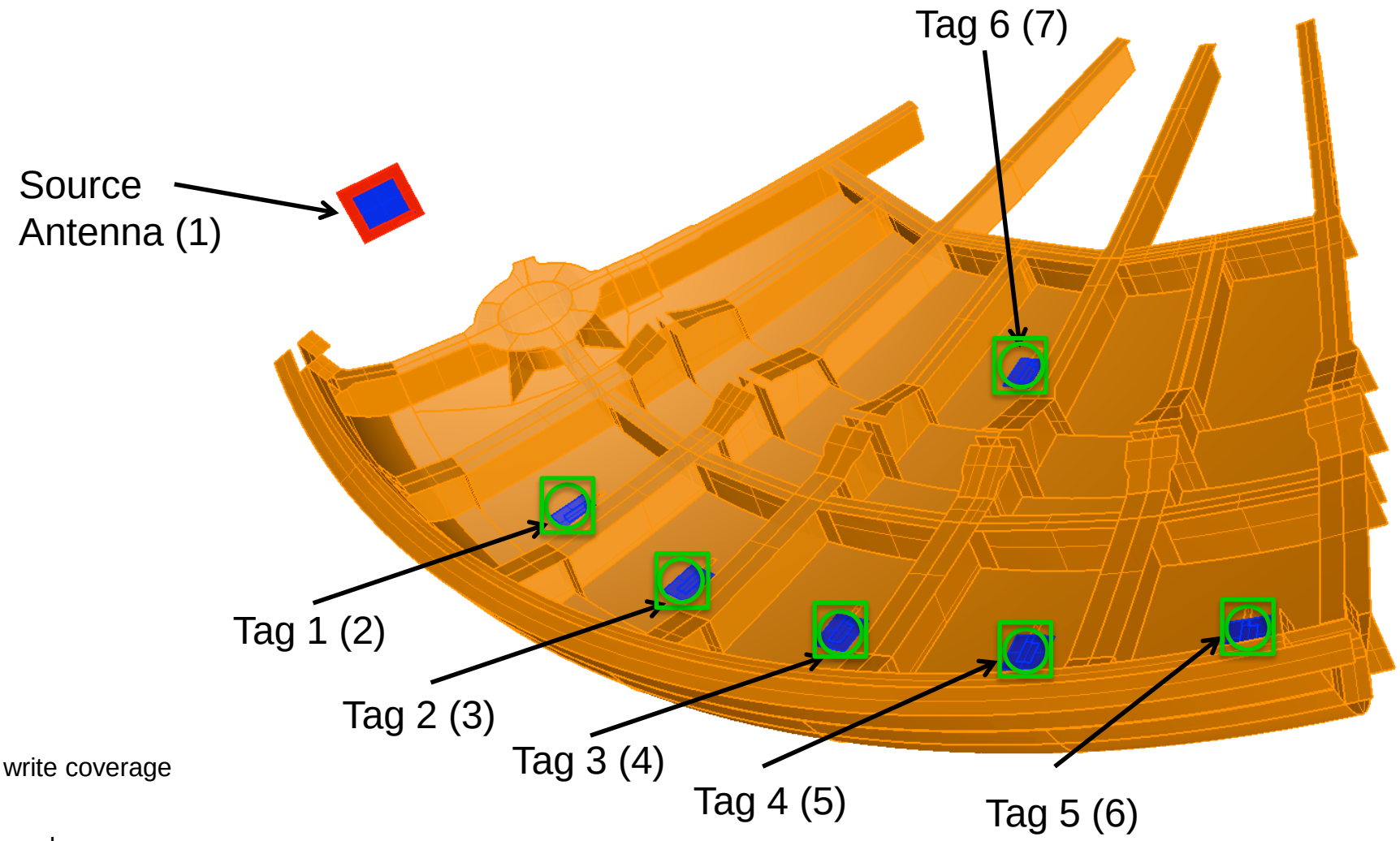
Sector D Heat Shield Modeling



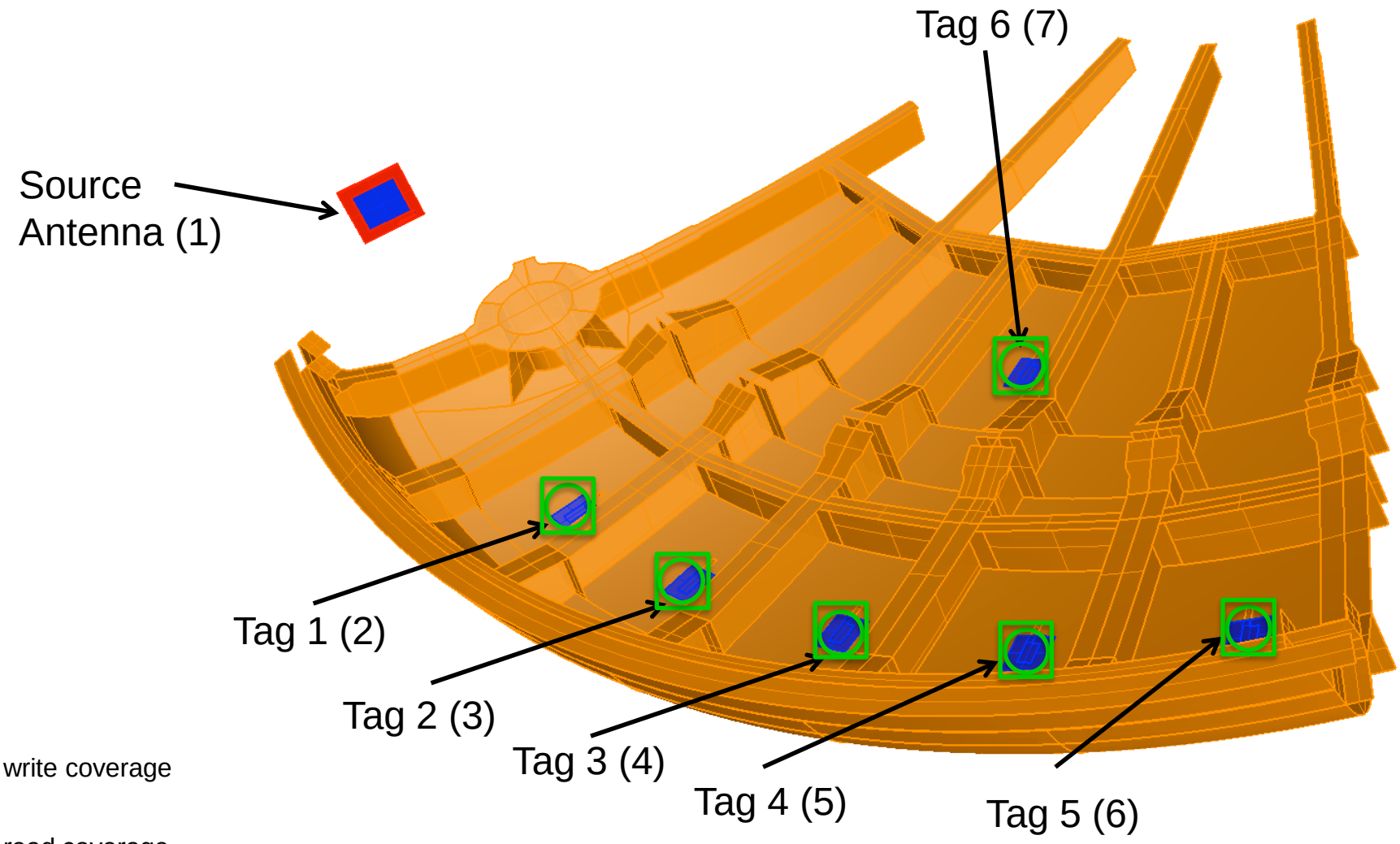
Sector D Heat Shield Modeling (cont.)



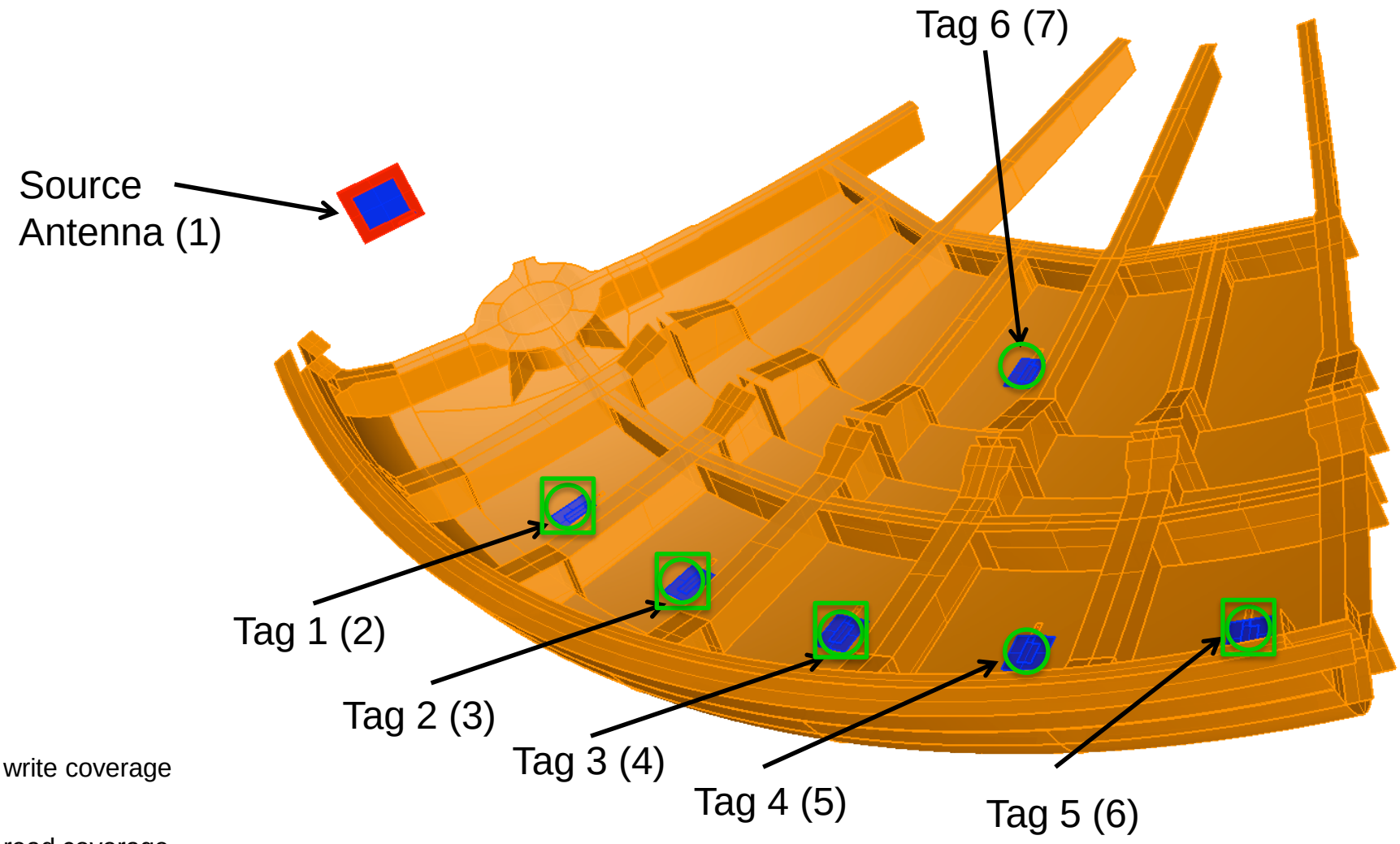
Sector D Heat Shield
1W Coverage



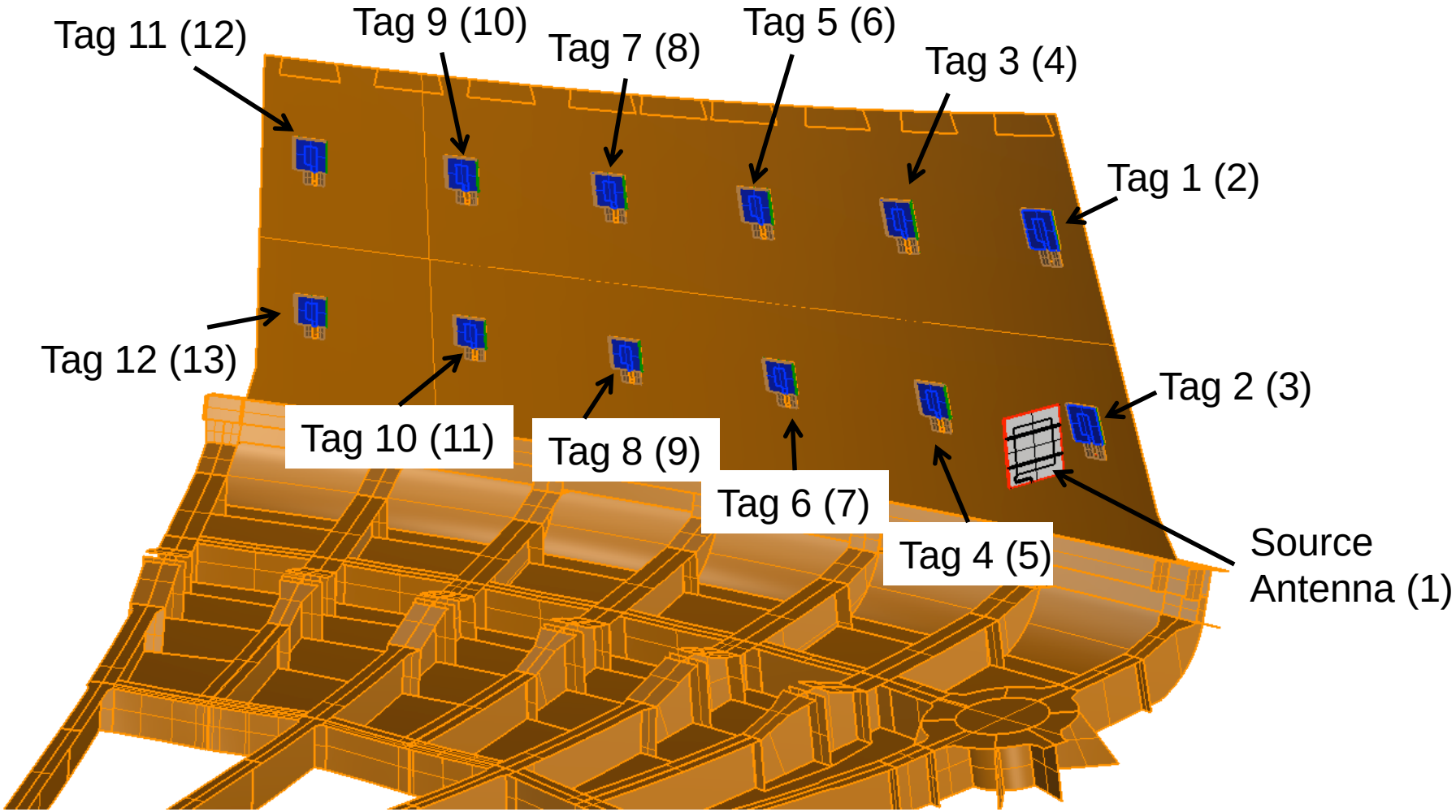
Sector D Heat Shield
100mW Coverage



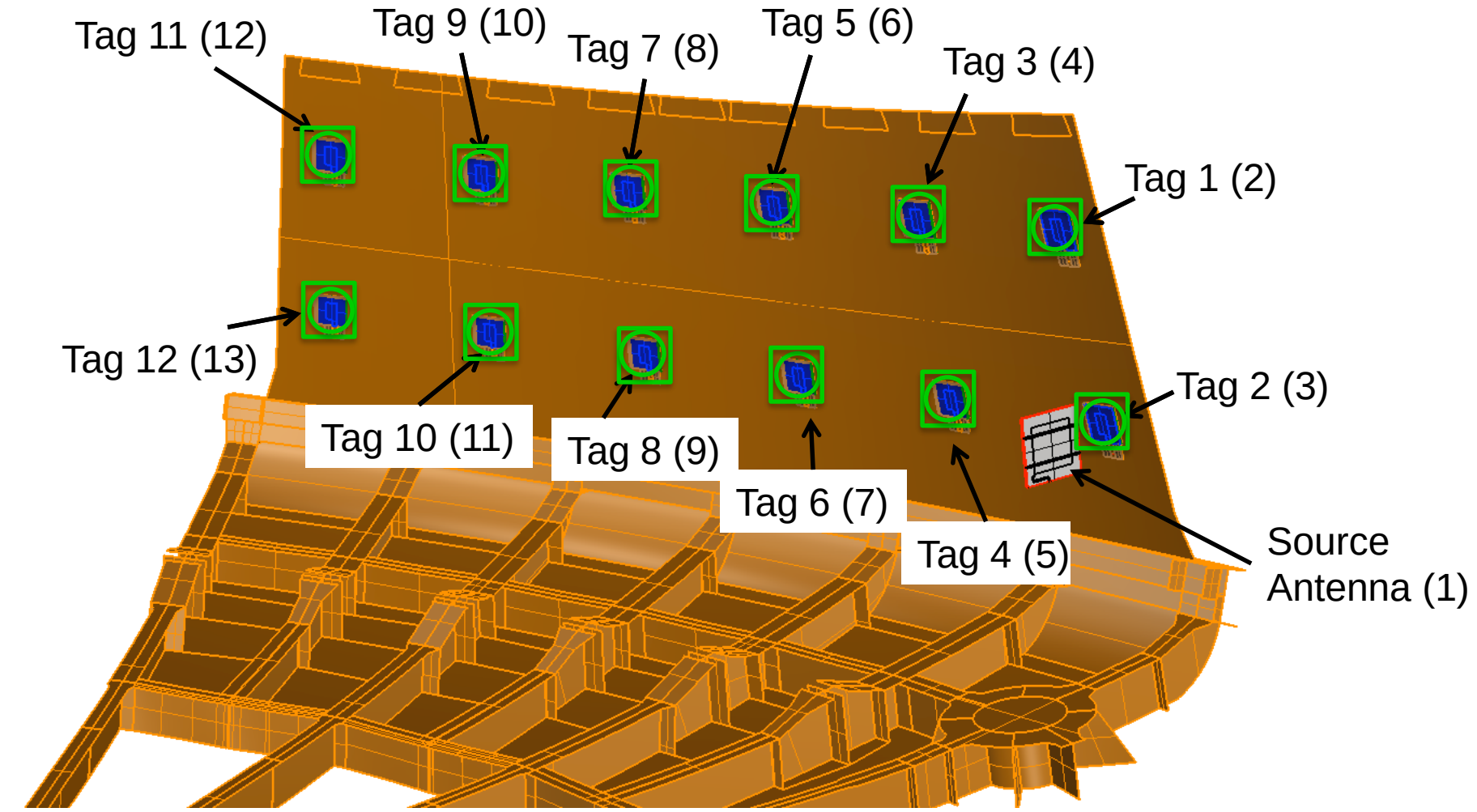
Sector D Heat Shield
30mW Coverage



Sector D Backshell Modeling



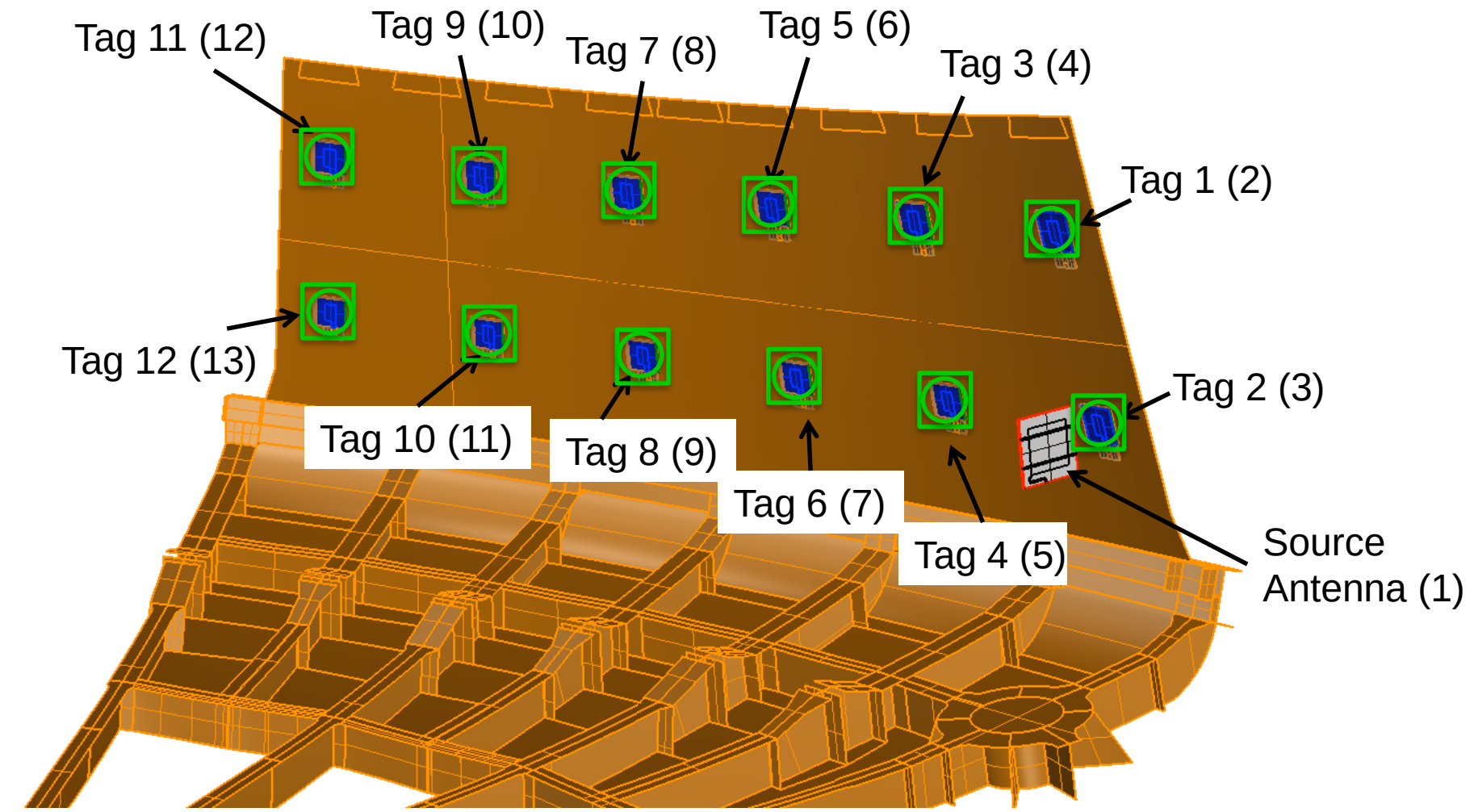
Sector D Backshell
1W Coverage



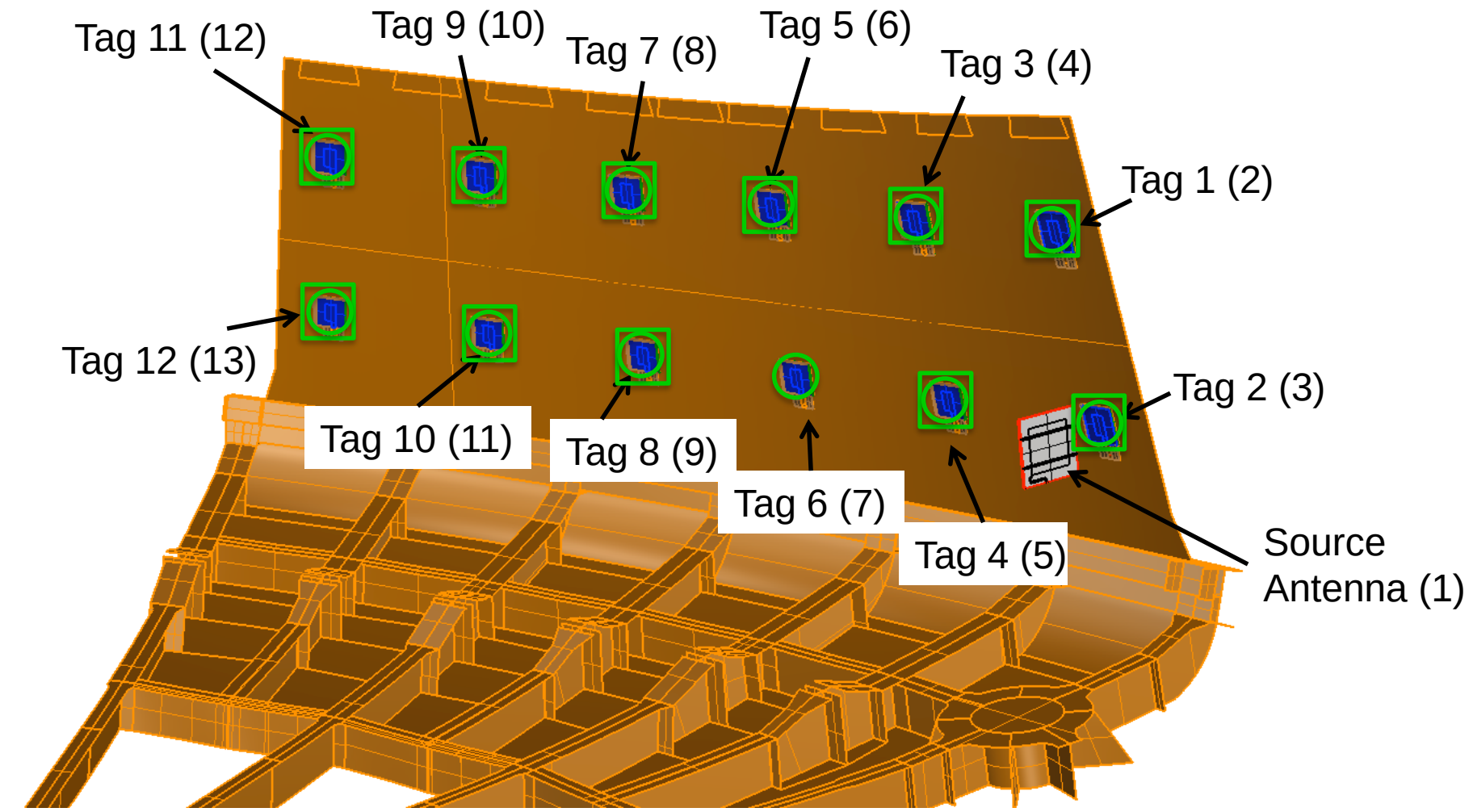
write coverage

read coverage

Sector D Backshell
100mW Coverage



Sector D Backshell
30mW Coverage



Aft Bay Sector E: “most cluttered”

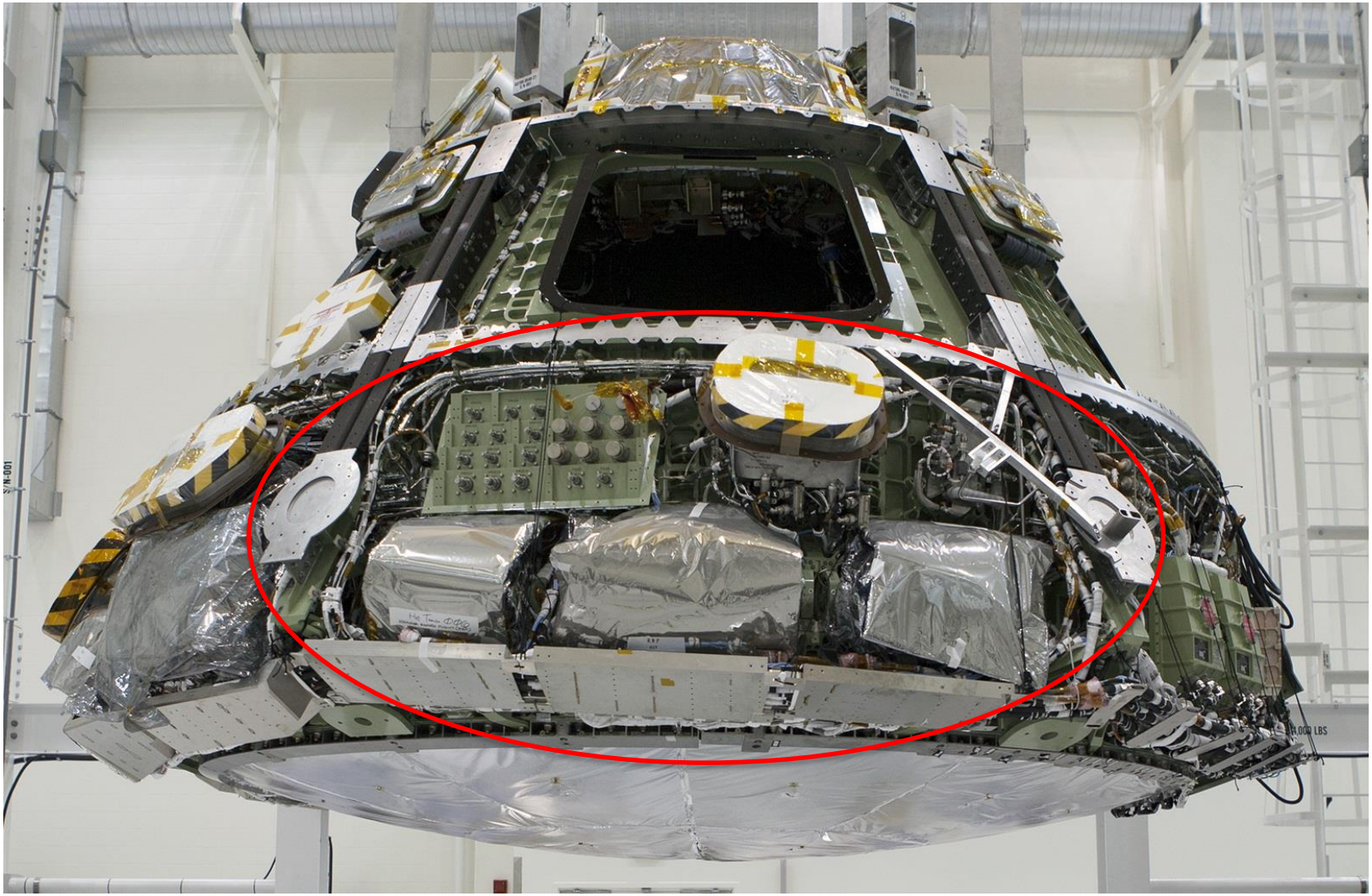
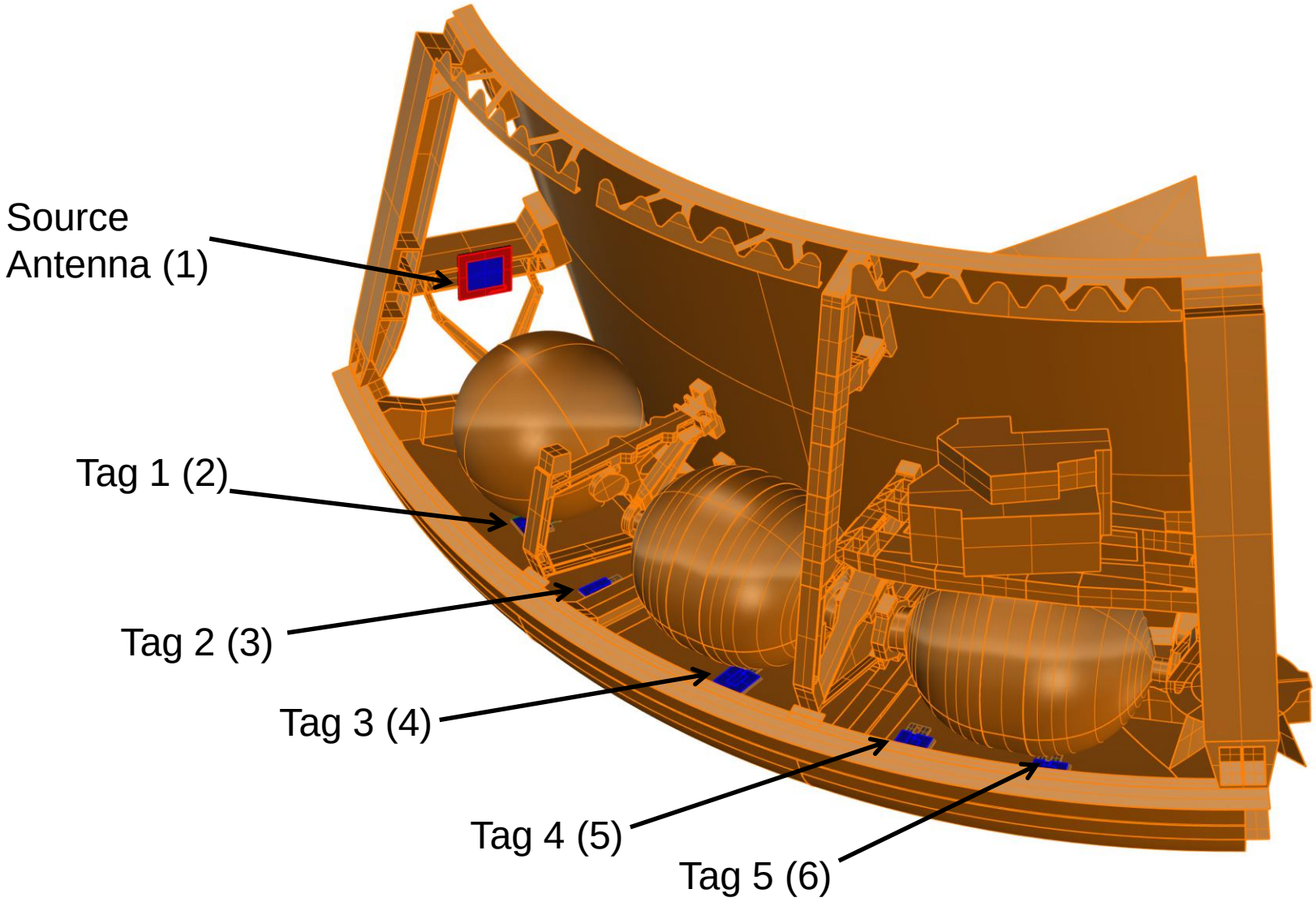
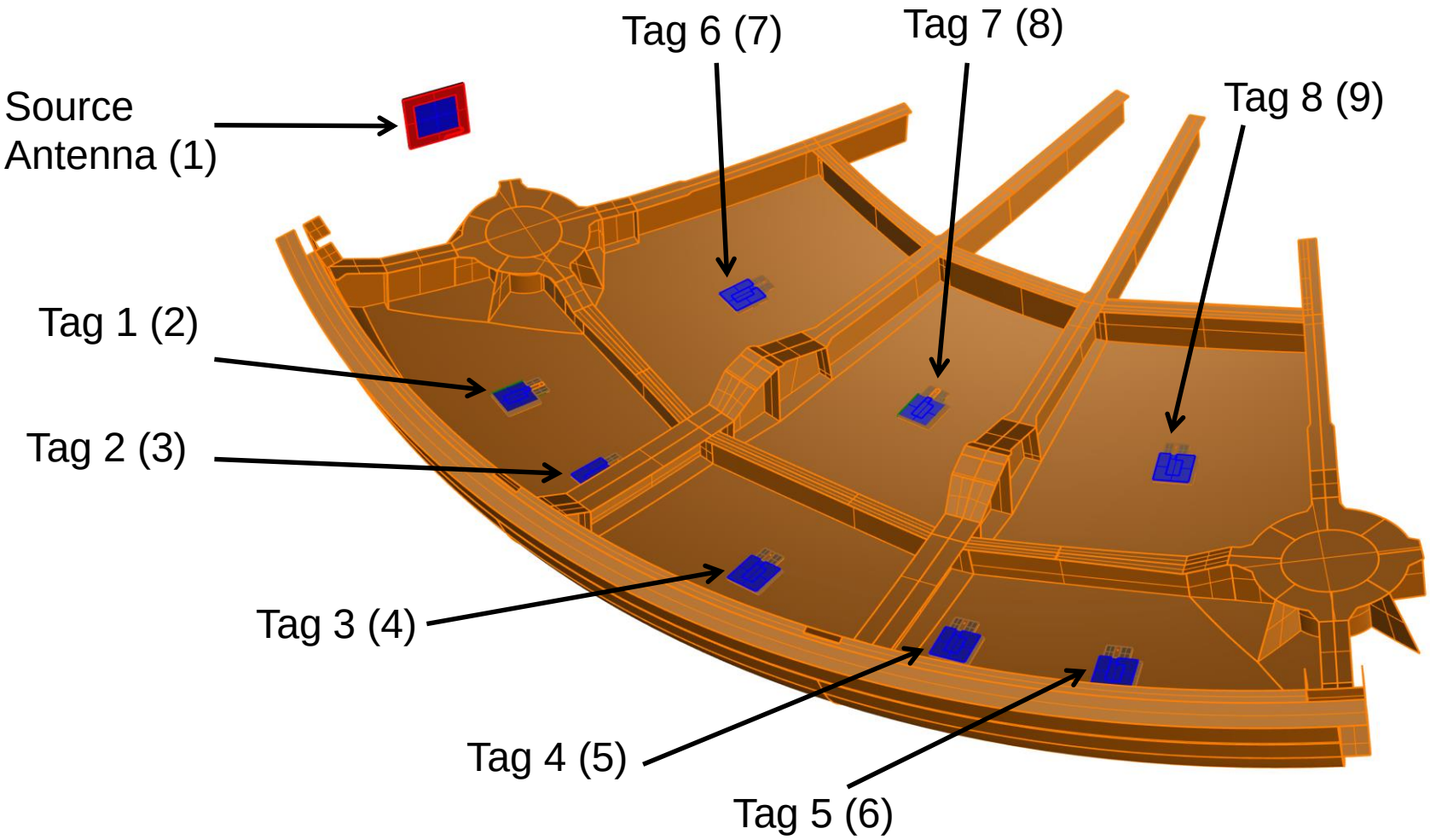


image source: nasa.gov

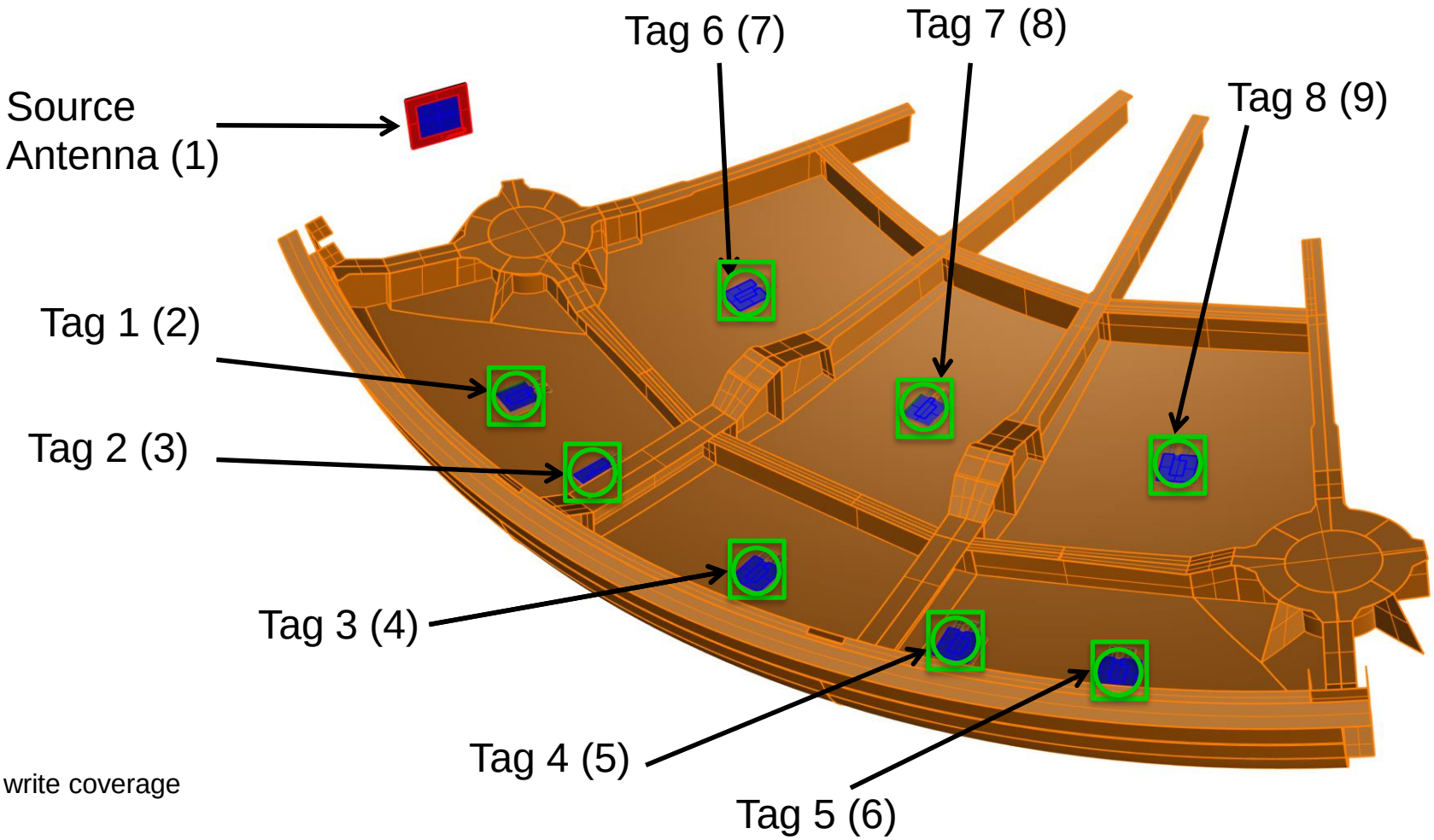
Sector E Heat Shield Modeling



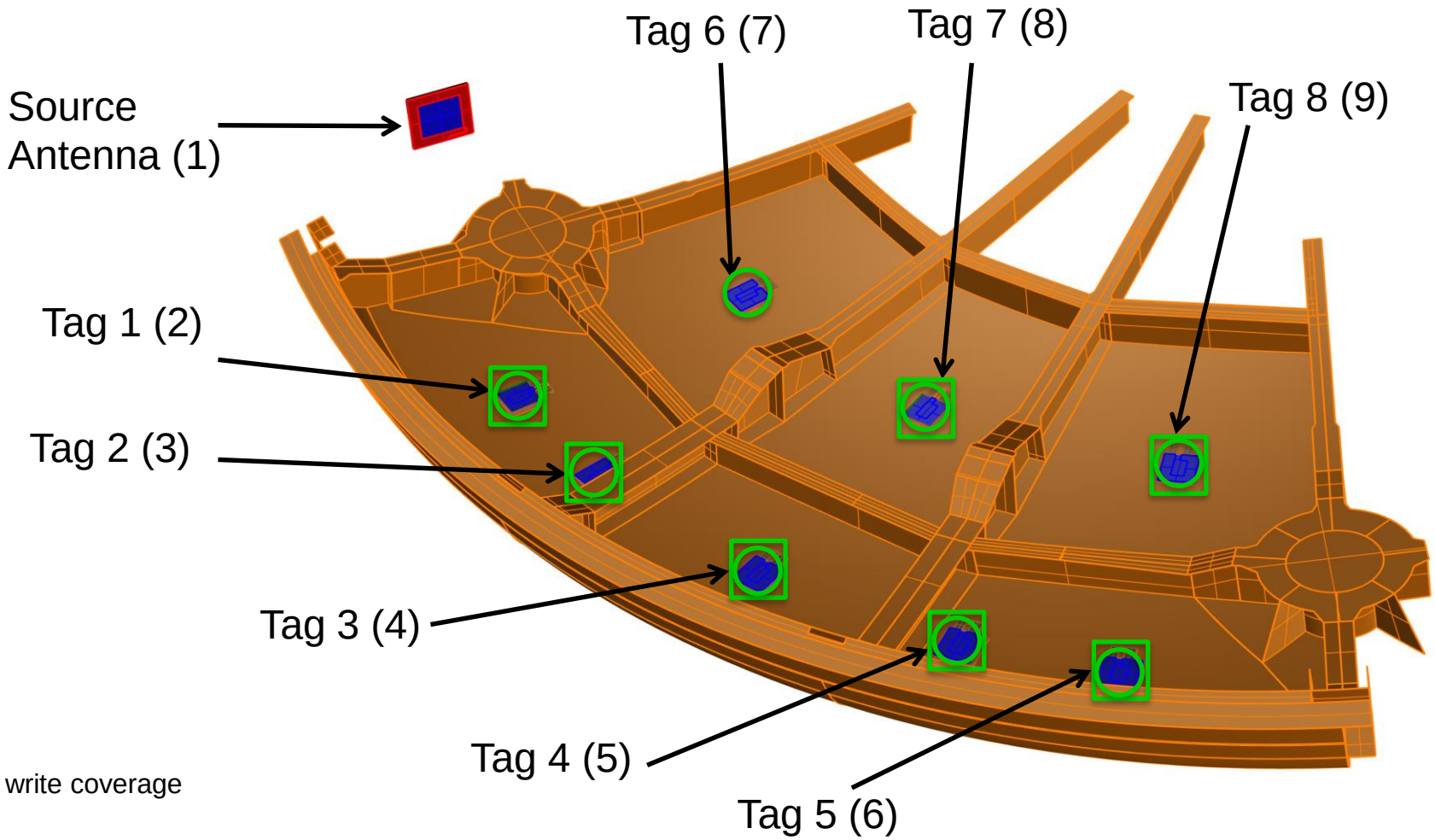
Sector E Heat Shield Modeling (cont.)



Sector E Heat Shield
1W Coverage



Sector E Heat Shield
100mW Coverage



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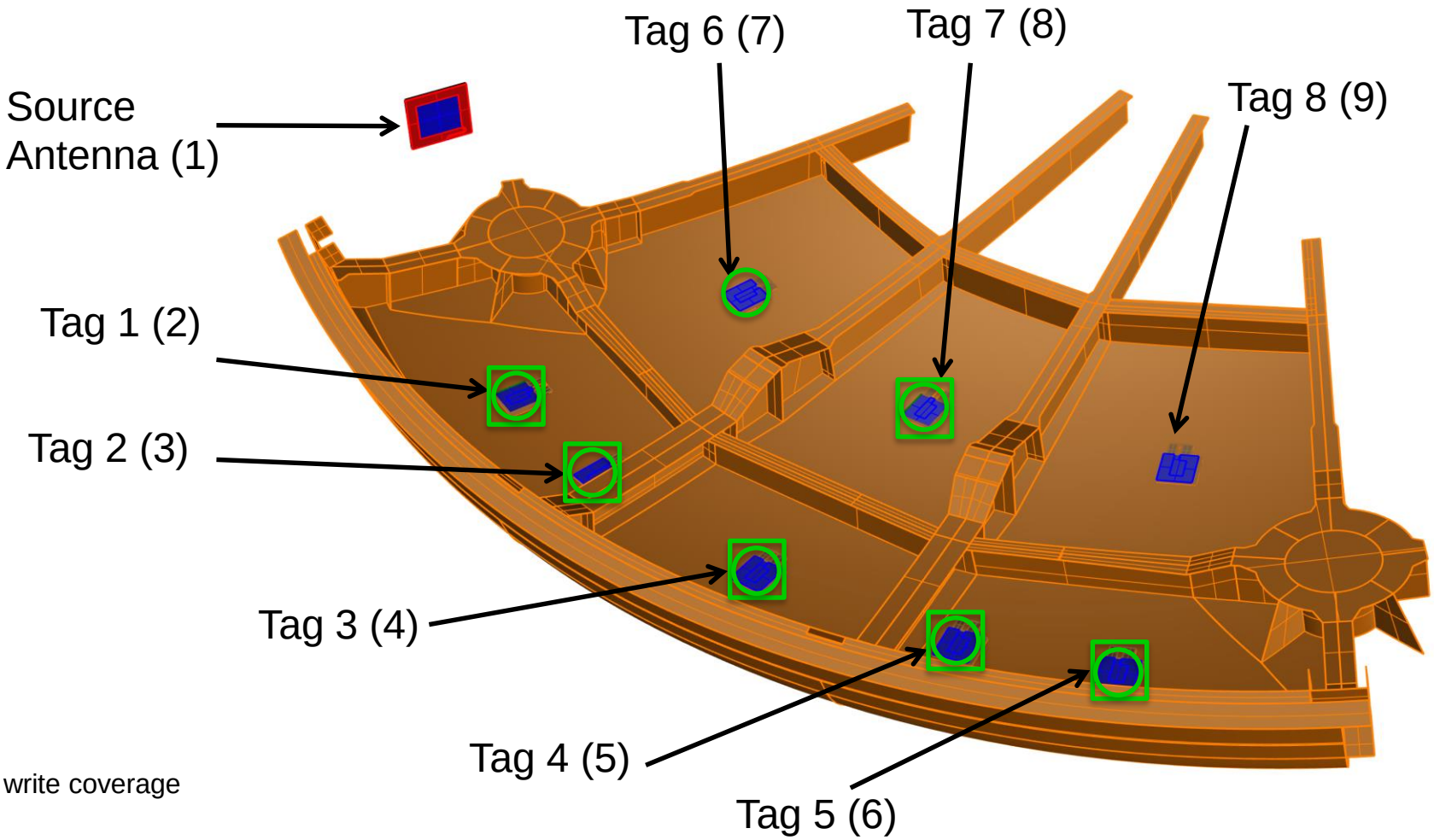
30mW Coverage



Summary of Accomplishments

- **Extremely low-mass sensor architecture demonstrated:**
  - tag mass (textile antenna/housing): 34.5 g./tag (0.08 lbs./tag)
  - infrastructure mass (1 IRIS interrogators + 2 REALM-1 antennas): 1.2 kg (2.70 lbs.)
    - plus cabling/fasteners
  - mass trade scales well as tags added
    - e.g., 150 tags → ~ 0.1 lbs./channel

- **Extremely battery-efficient sensor architecture demonstrated:**
  - 9.4 years hibernation time (BR2330A battery)
  - 223 days 10Hz TC streaming (BR2330A)

- **Scalable architecture demonstrated:**
  - 50 10Hz tags/interrogator shown to date
  - approach can deliver data with approx. 0% packet loss (50-tag population)
  - >100 10 Hz tags/interrogator seems likely based on experiments to date
    - further scalable with planed improvements in RFID hardware

- **RF coverage risk significantly bought down**
  - CEM analysis confirms coverage from 100mW – 1W interrogator output power
  - mockup testing ongoing to confirm

Project Status and Forward Work

- **Preparing IRIS for commercialization / flight demonstration opportunities**
- **Environmental testing completed to date:**
  - Electromagnetic Interference / Electromagnetic Compatibility
  - Vibration
  - Thermal/Vacuum
- **Higher data-rate extensions have been explored/prototyped**
- **Flight demonstration opportunities are being sought**
- **Development will continue to:**
  - decrease system mass
  - increase battery lifetimes, explore harvested power
  - increase data rate
  - increase reference designs for sensors of interest
    - e.g., optical recession sensors

Contact

Raymond Wagner, NASA/JSC-EV8

raymond.s.wagner@nasa.gov

(281) 244-2428