Homeland Defense & Security
Information Analysis Center

RFID for Continuous Monitoring in Dynamic Environments

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HDIAC Subject Matter Expert

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Introduction

HDIAC and Today's Topic

HDIAC Overview

What is the Homeland Defense & Security Information Analysis Center (HDIAC)?

One of three Department of Defense Information Analysis Centers

Responsible for acquiring, analyzing, and disseminating relevant scientific and technical information, in each of its eight focus areas, in support of the DoD and U.S. government R&D activities

HDIAC's Mission

Our mission is to be the go-to R&D/S&T and RDT&E leader within the homeland defense and security (HDS) community, by providing timely and relevant information, superior technical solutions, and quality products to the DoD and HDS Communities of Interest/Communities of Practice.

HDIAC Overview

HDIAC Subject Matter Expert (SME) Network

HDIAC SMEs are experts in their field(s), and, typically, have been published in technical journals and publications.

SMEs are involved in a variety of HDIAC activities

- Authoring HDIAC Journal articles
- Answering HDIAC Technical Inquiries
- Engaging in active discussions in the HDIAC Community
- Assisting with HDIAC Core Analysis Tasks
- Presenting webinars

If you are interested in applying to become a SME, please visit HDIAC.org or email info@hdiac.org.

Overview: Passive RFID Systems for DoD Applications

- **Passive RFID systems are typically used to identify and track assets—inventory, supplies, passports**
- **DoD has used such systems to add "automated visibility" to supply chains since 2005**
- **Recent advances in sensor technology have produced sensing systems significantly reduced in size, weight, and power**
- **Connecting distributed sensors via passive RFID communication allows for pervasive "intelligent monitoring" of assets**
    - Extremely low-mass, battery-efficient, and long-lifecycle
    - Scalable for broad-area application
- **Near-term applications to dynamic environments include**
    - Structural health monitoring (e.g., infrastructure; aerospace)
    - Warfighter sensoring via e-textile antennas

Raymond Wagner, Ph.D.

Wireless RFID Sensing Engineer, NASA-Johnson Space Center

Raymond Wagner, Ph.D., leads the wireless sensor network research and development program at NASA-Johnson Space Center, and he is involved in related programs for development of wireless communications systems for vehicle, habitat, and surface operations. He earned a Ph.D. in electrical engineering in 2007 as an NSF Graduate Research Fellow at Rice University with a thesis concerning distributed data processing algorithms for wireless sensor networks.

His research interests include RFID, passive and active wireless sensor networks, low-power embedded computing, and distributed signal processing, and he is active in standards development for international space agencies within the Consultative Committee for Space Data systems.

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 (10 Hz) 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:

(image credit: Creative Commons Attribution v. 2.0 generic)

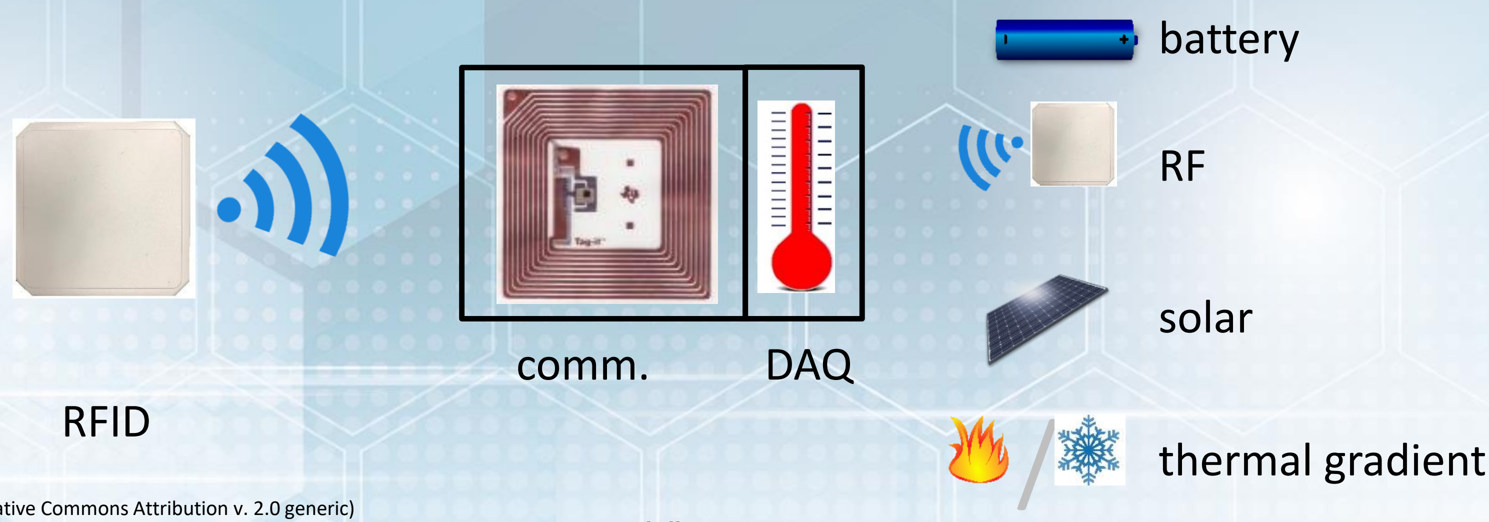
RFID for Sensing

But these same standards can transport sensor data as well:

(image credit: Creative Commons Attribution v. 2.0 generic)

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,…)



(image credit: Creative Commons Attribution v. 2.0 generic)

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)

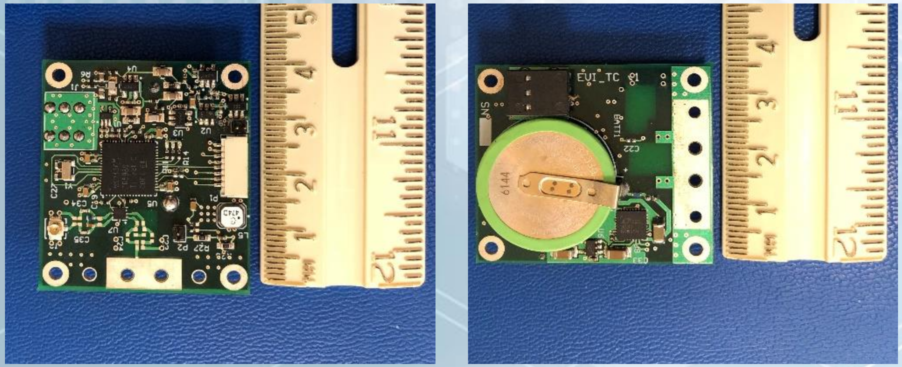
- 10.5 g.
  - 0.02 lbs.
- 3.5 cm. x 4 cm.
  - 1.4 in. X 1.6 in.
- BR2330A battery

E-textile (fabric) antenna

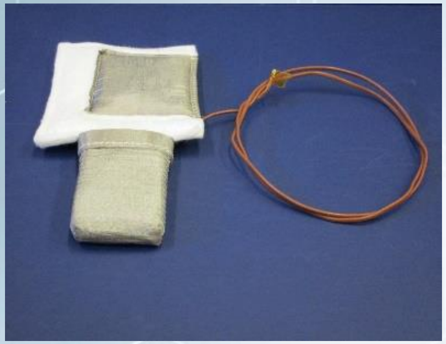
- direct textile mount
- 11 g.
  - 0.02 lbs.
- 10 cm. x 8.5 cm.
  - 3.9 in. x 3.3 in.

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

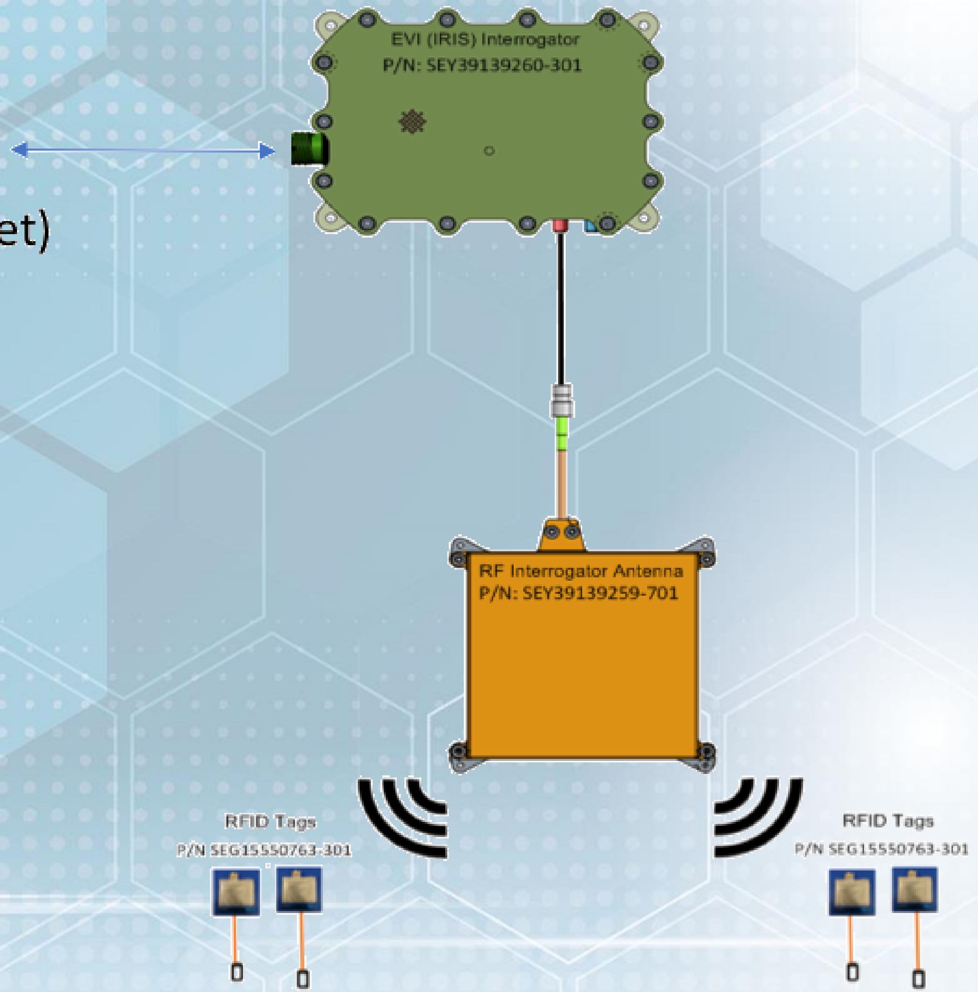
- Low-mass 900 MHz RFID antenna
- Custom designed for ISS inventory management work
- Harvests most of mass reductions through housing re-design

Mass (Un-optimized):

- 377 g.
  - 0.83 lbs.

System Diagram

Vehicle
Power/Data
(28VDC/Ethernet)



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**

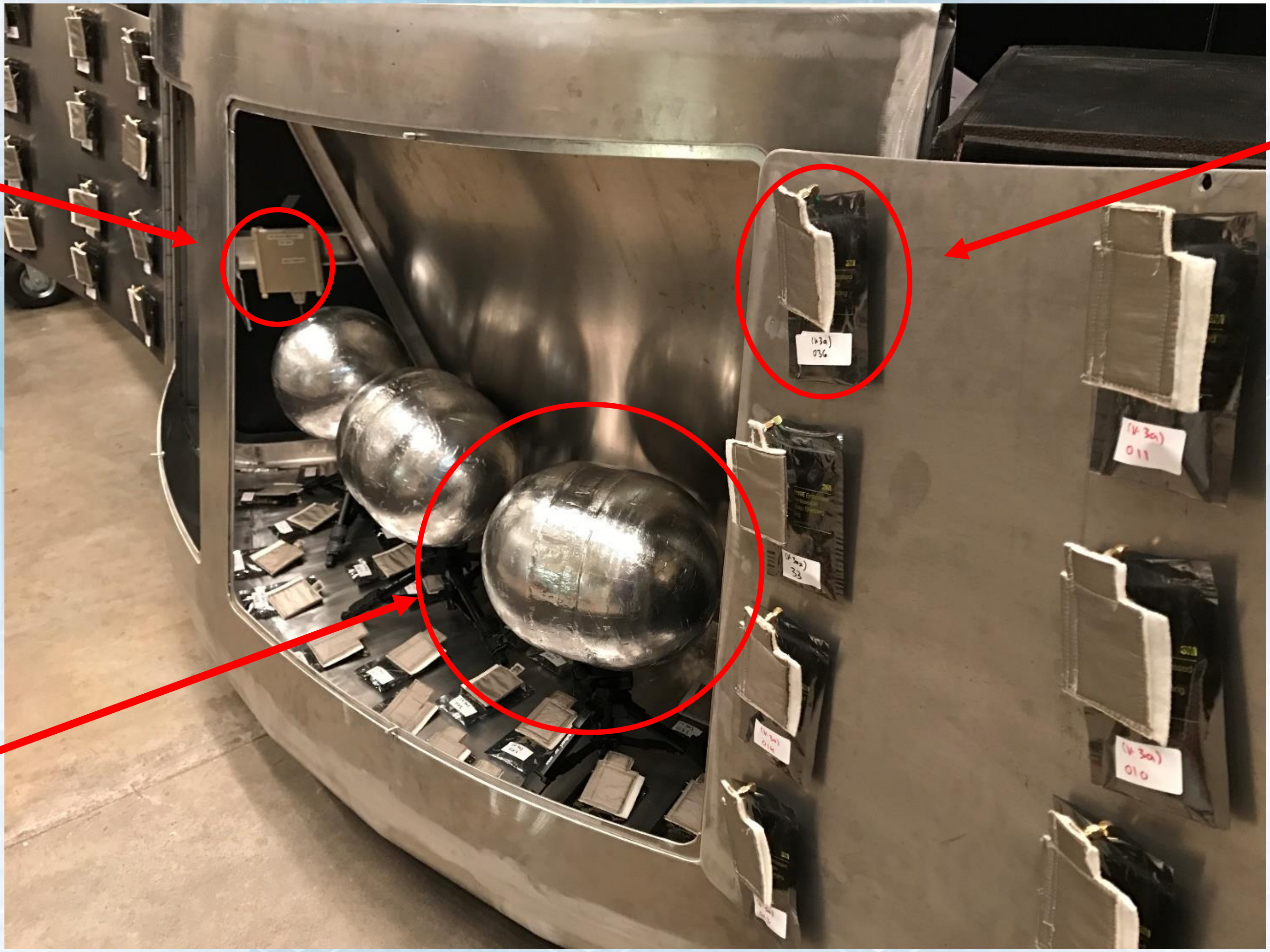
exterior

interior (populated)

Scaling/Throughput Test Environment

REALM-1 antenna

TC sensor tag



hydrazine tank mockup

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"

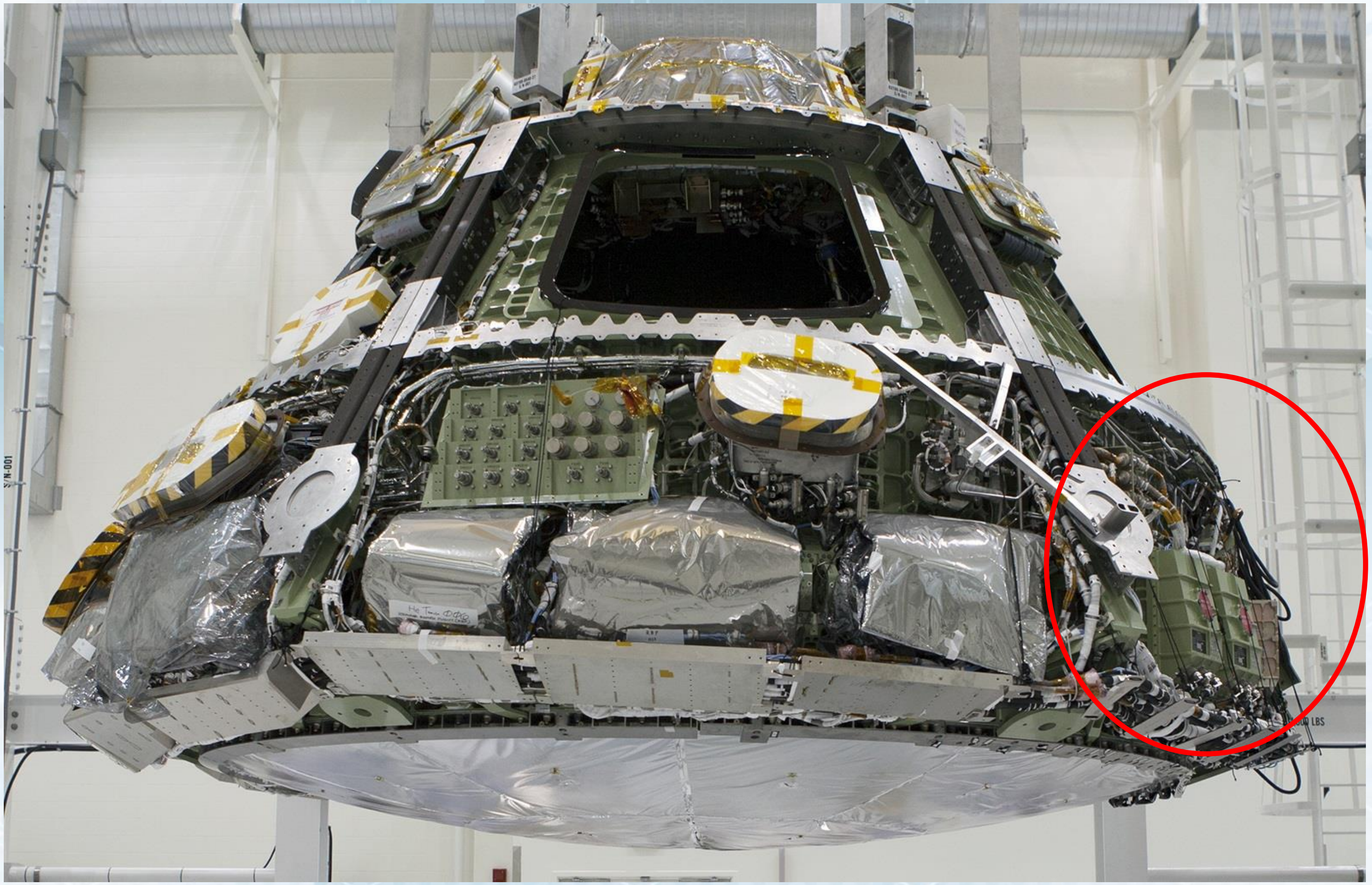
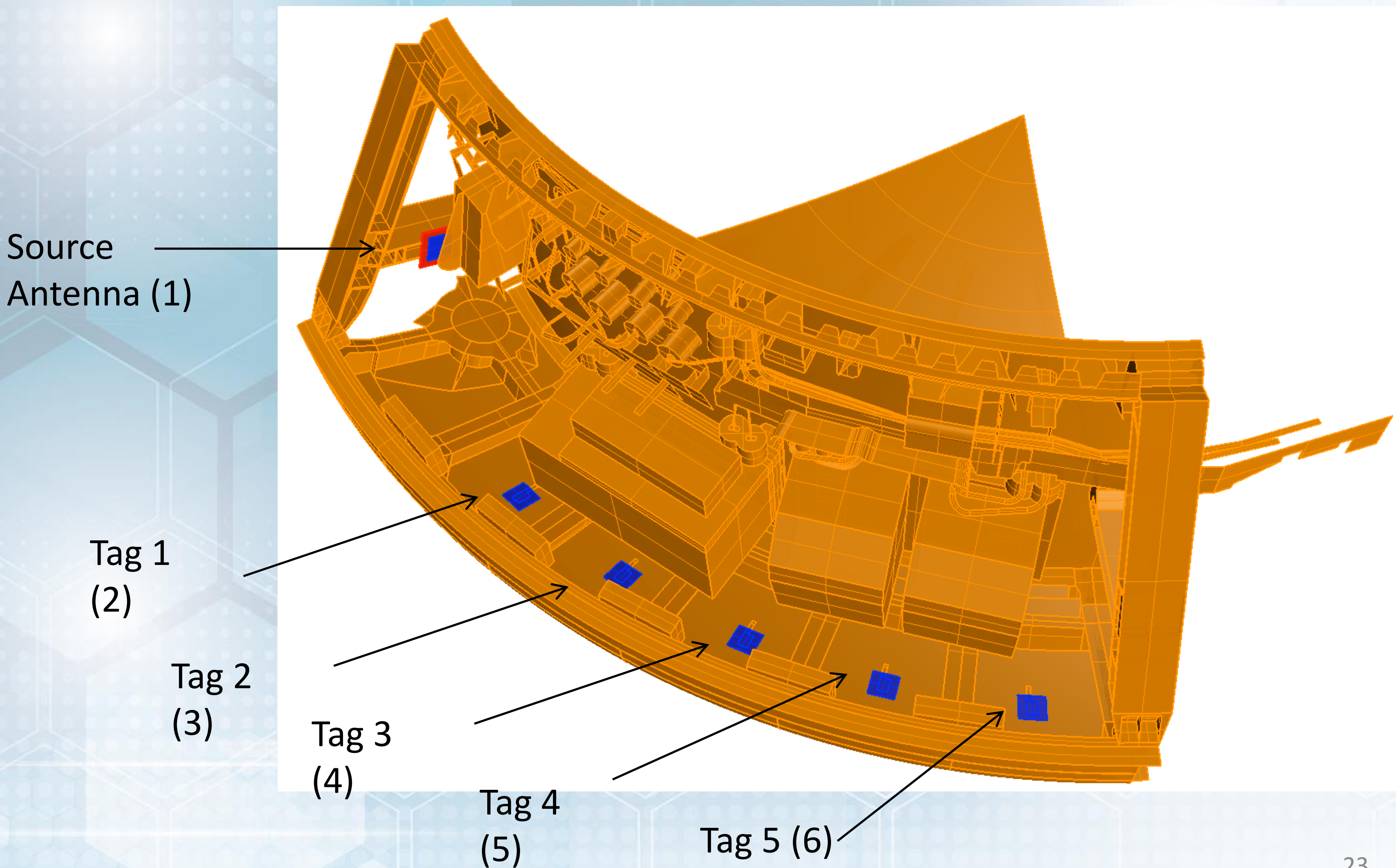
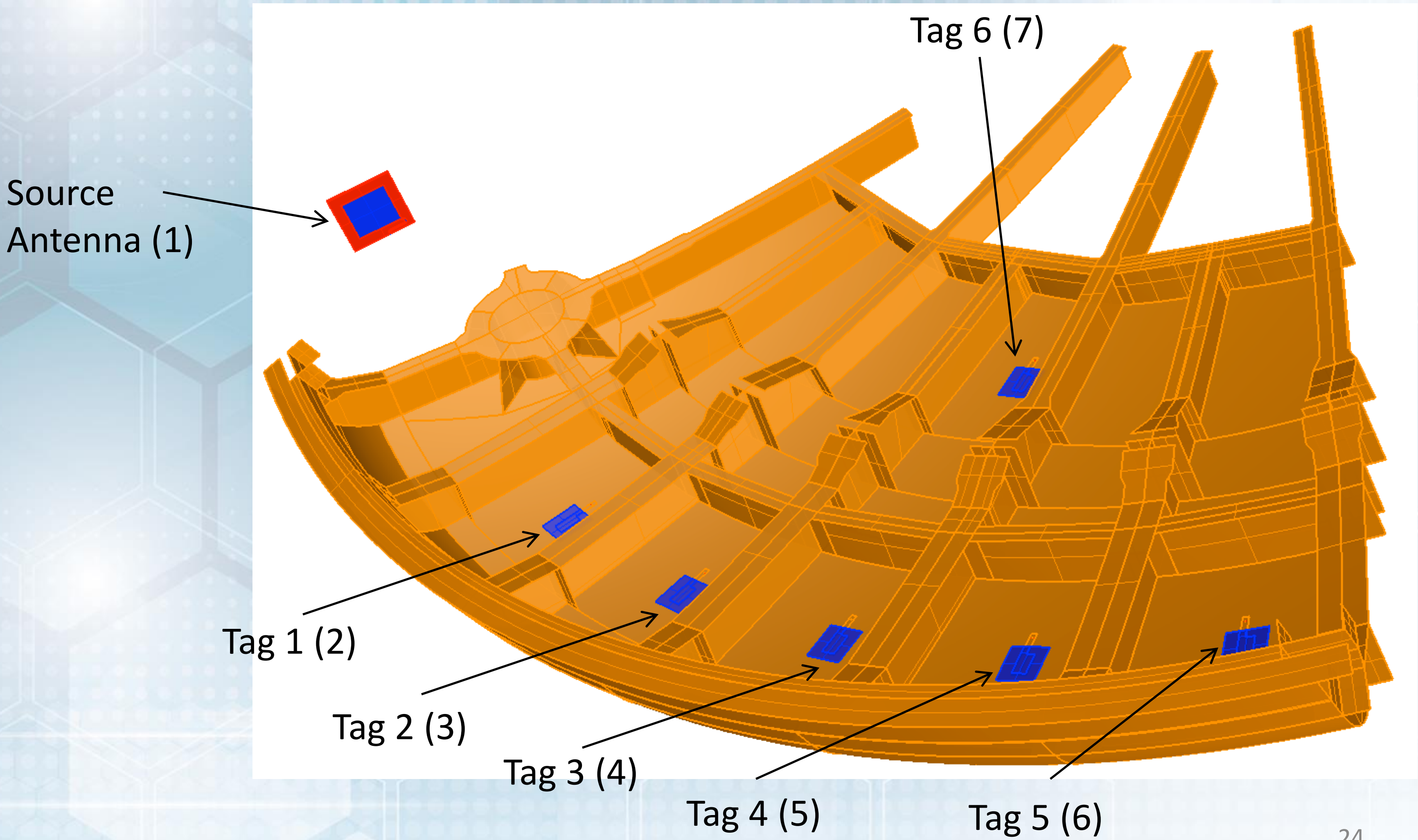


image source: nasa.gov

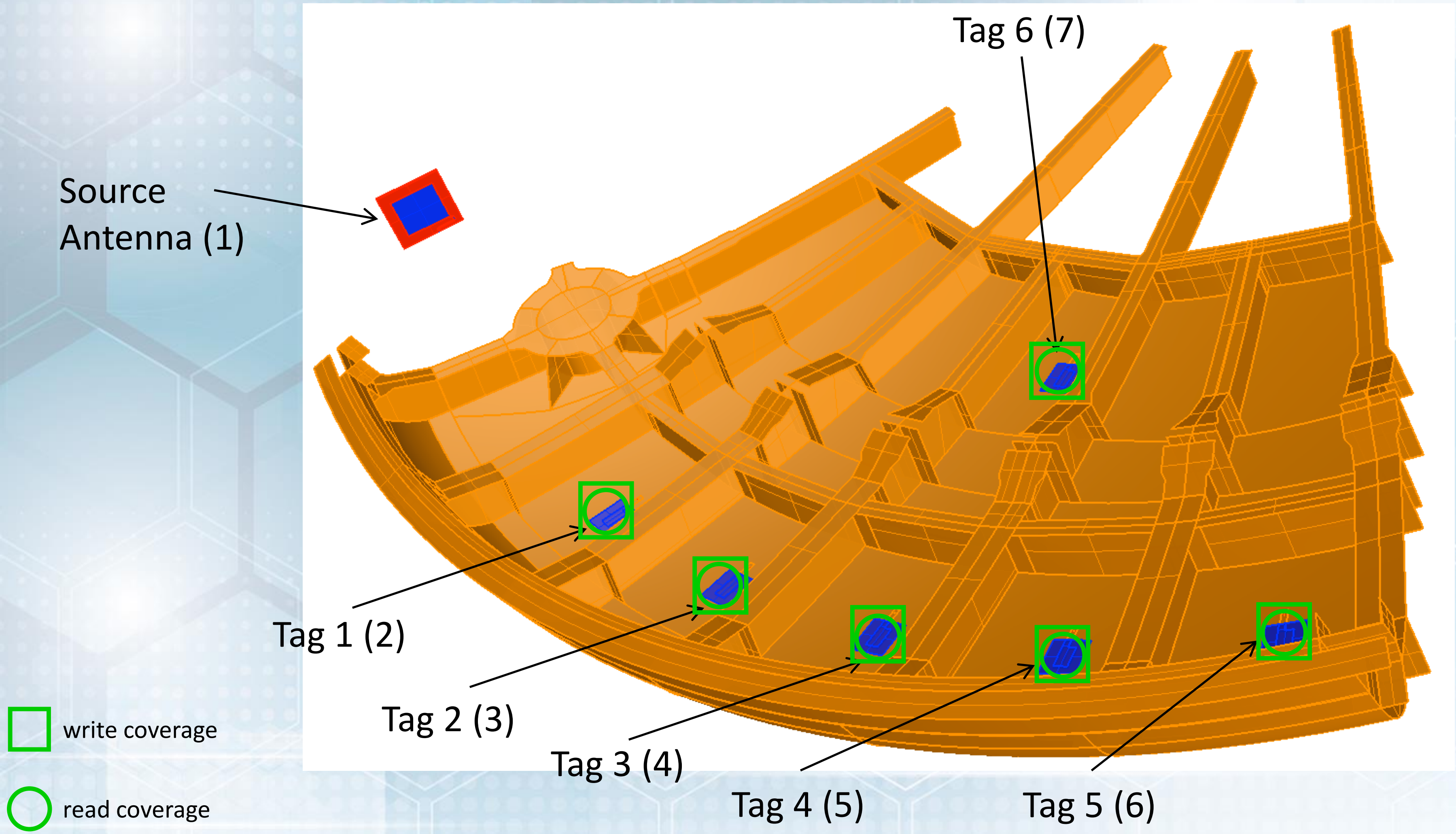
Sector D Heat Shield Modeling



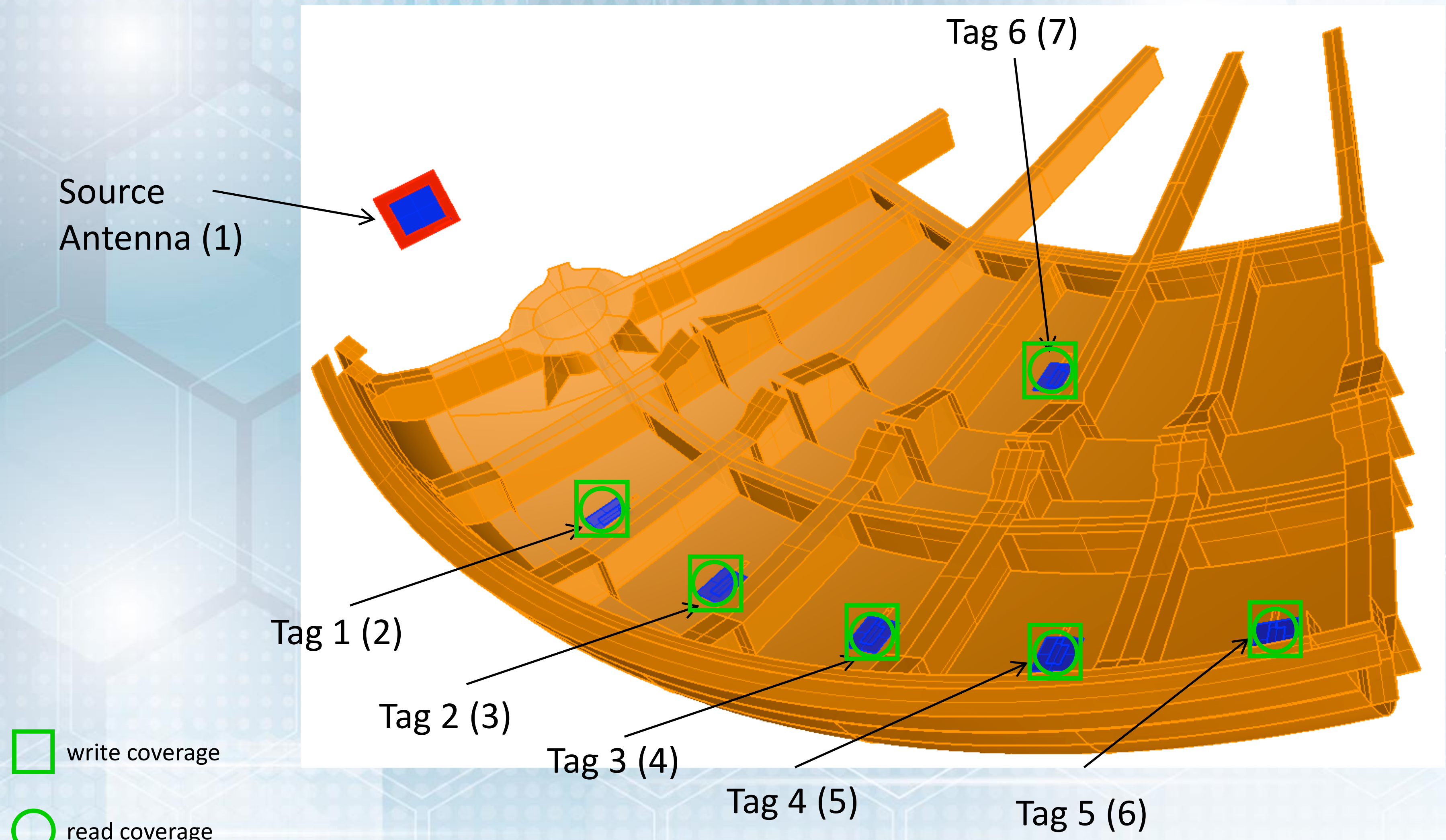
Sector D Heat Shield Modeling (cont.)



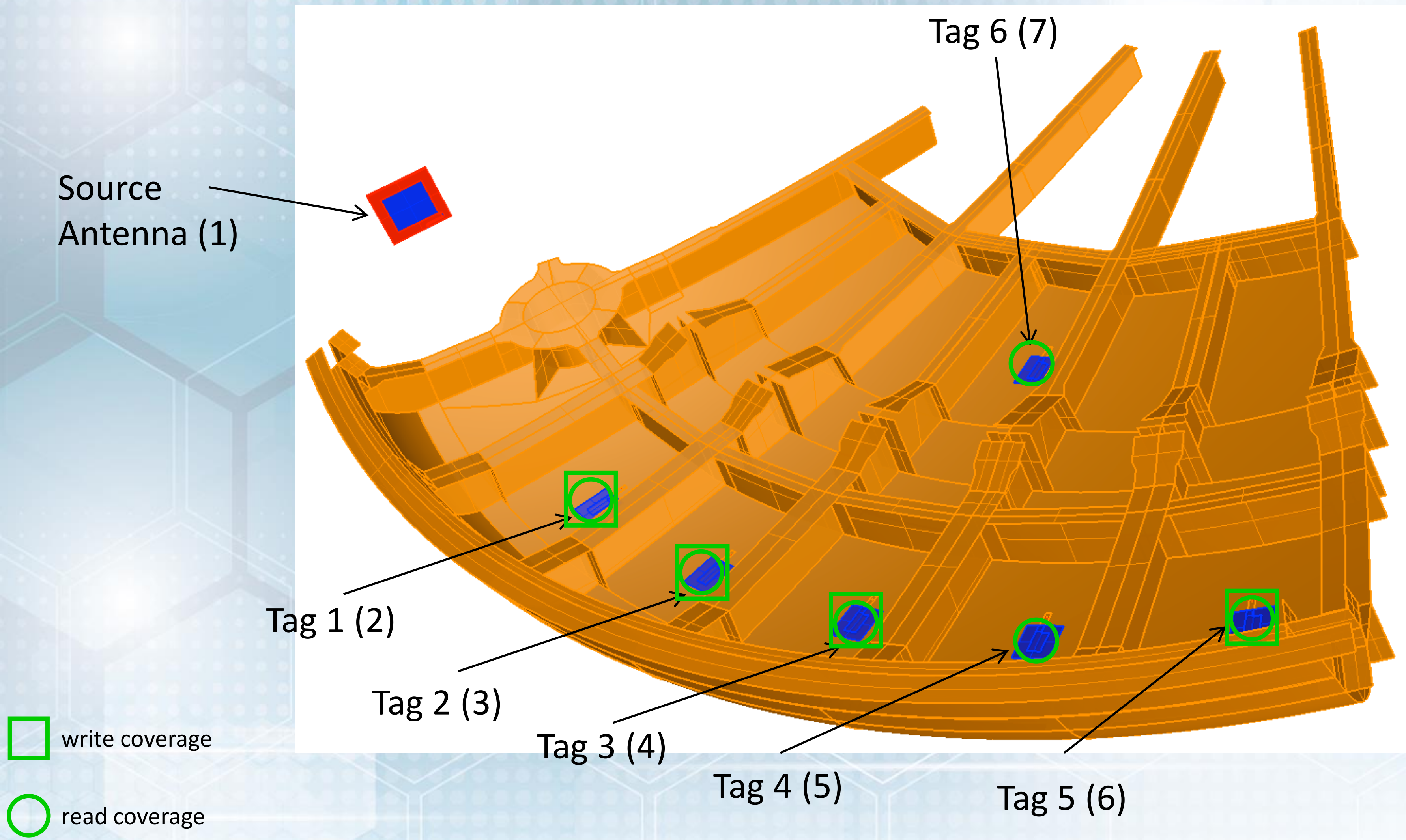
Sector D Heat Shield 1W Coverage



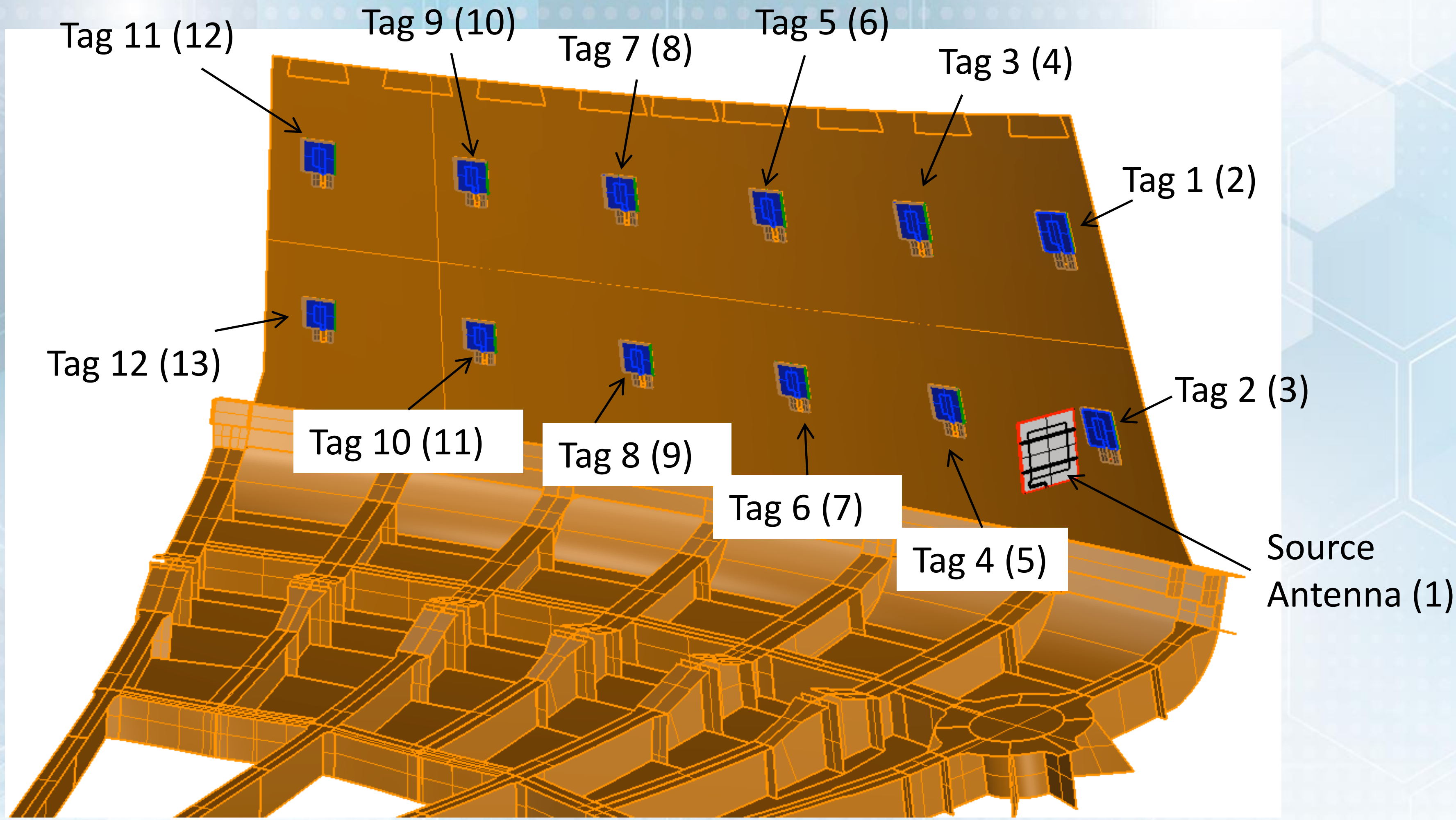
Sector D Heat Shield 100mW Coverage



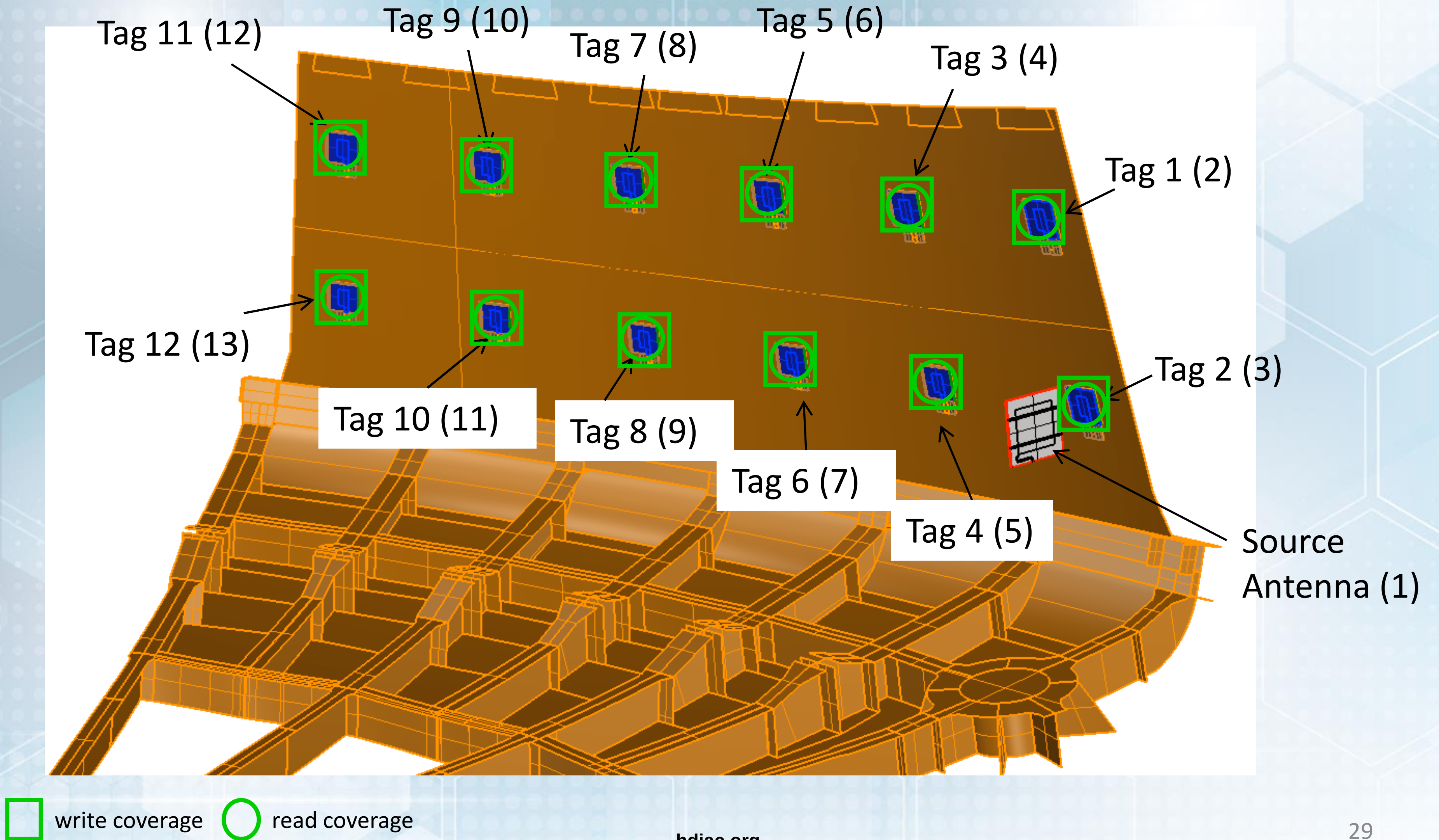
Sector D Heat Shield 30mW Coverage



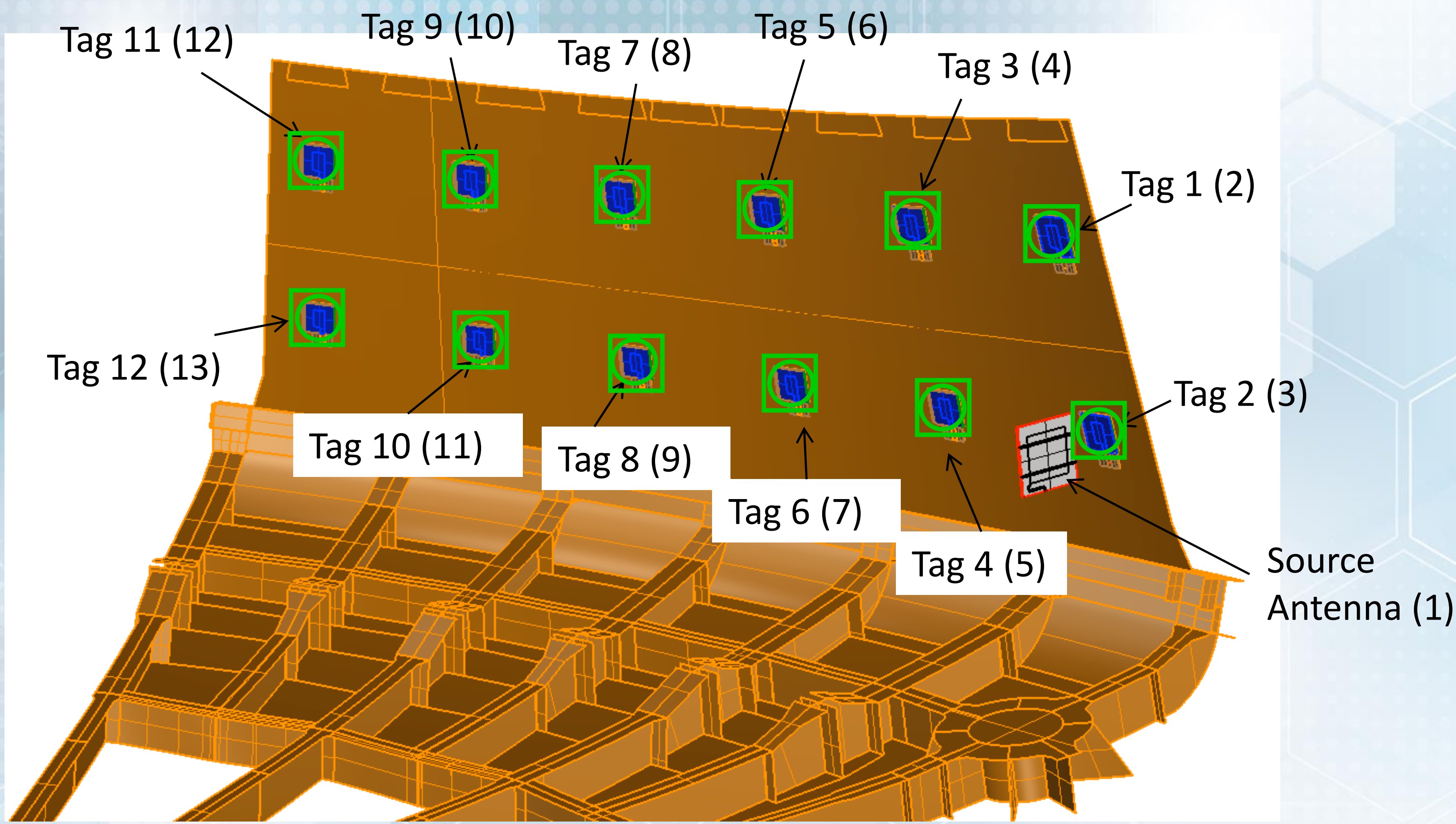
Sector D Backshell Modeling



Sector D Backshell 1W Coverage

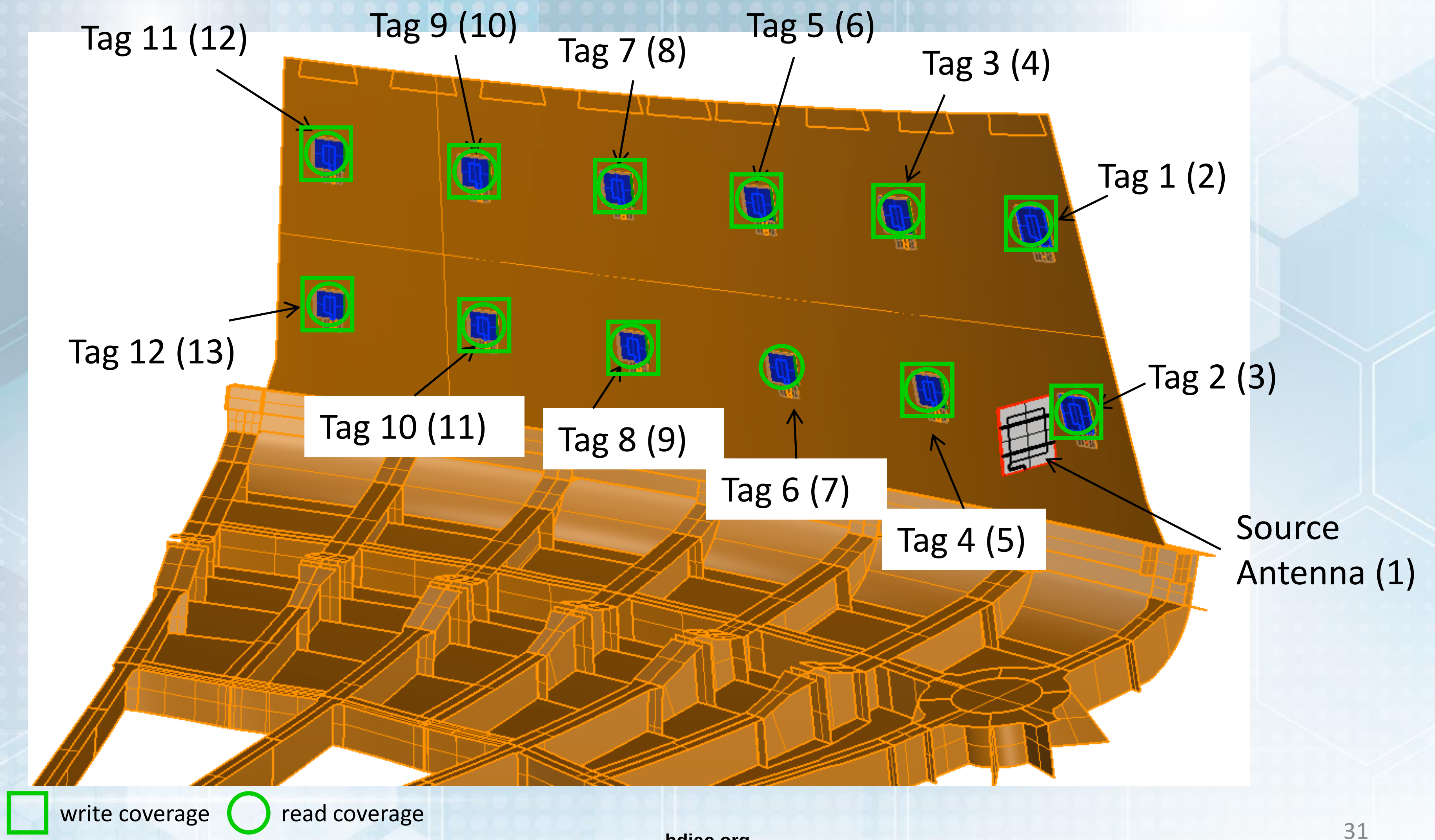


Sector D Backshell 100mW Coverage



write coverage read coverage

Sector D Backshell 30mW Coverage



Aft Bay Sector E: “Most Cluttered”

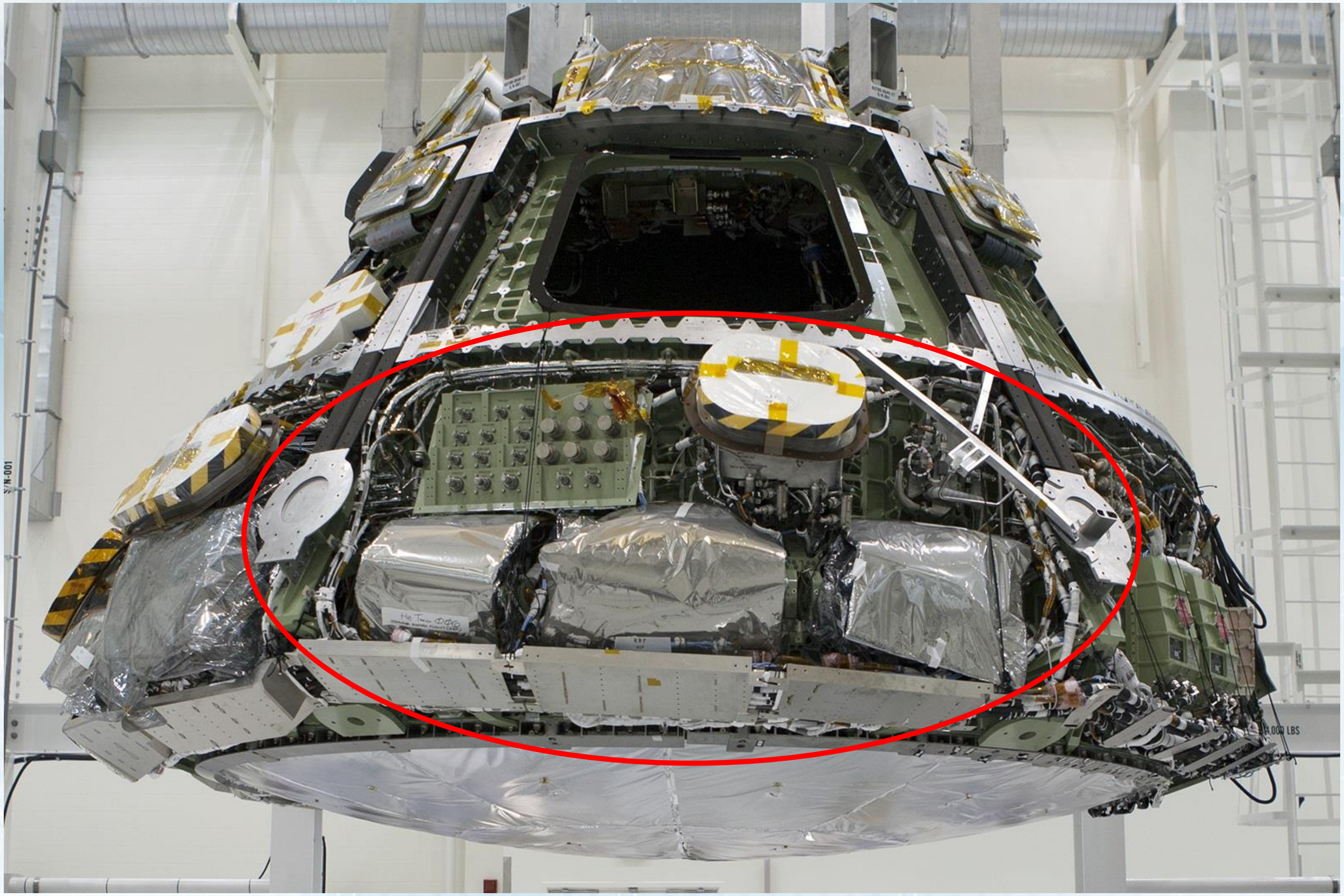
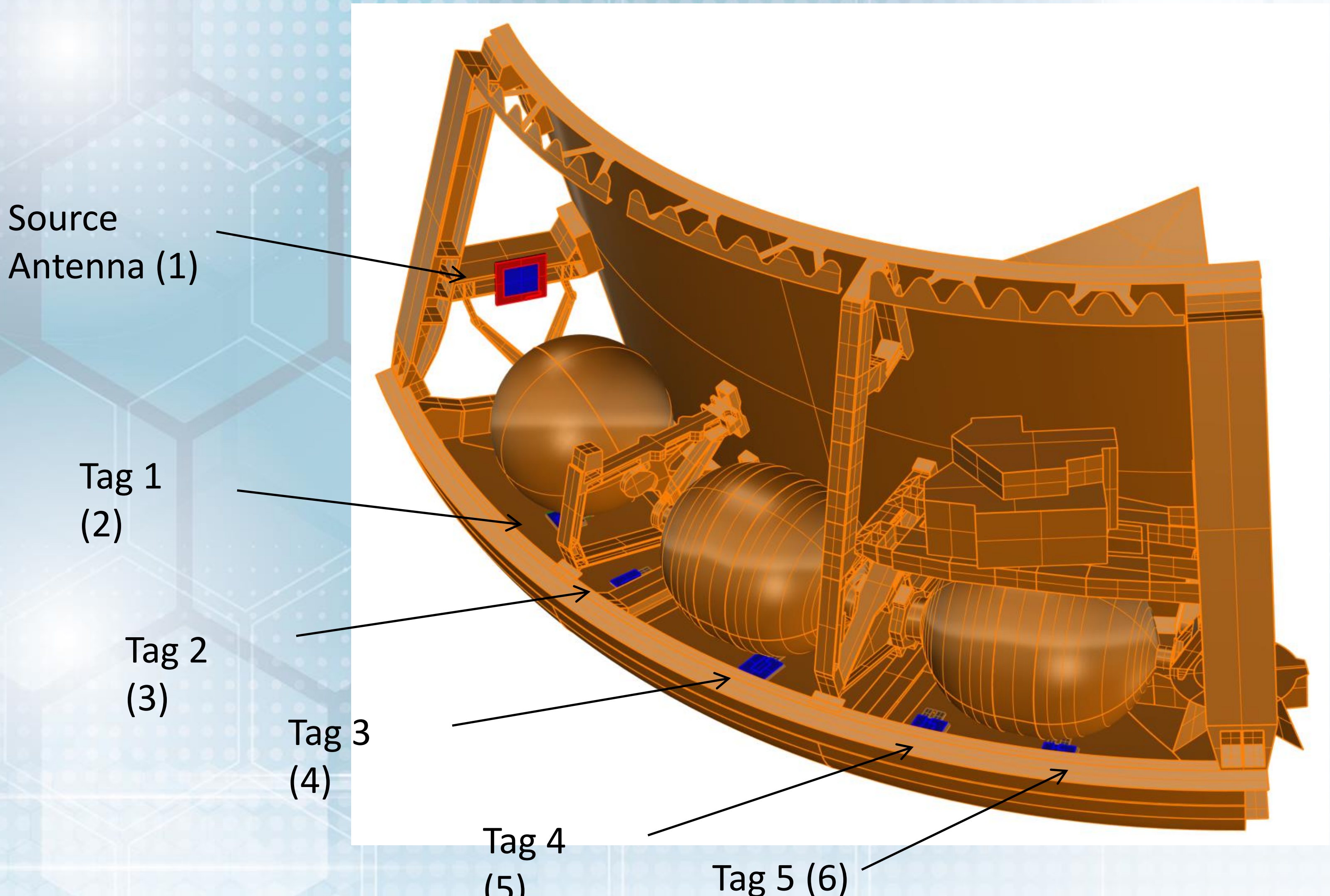
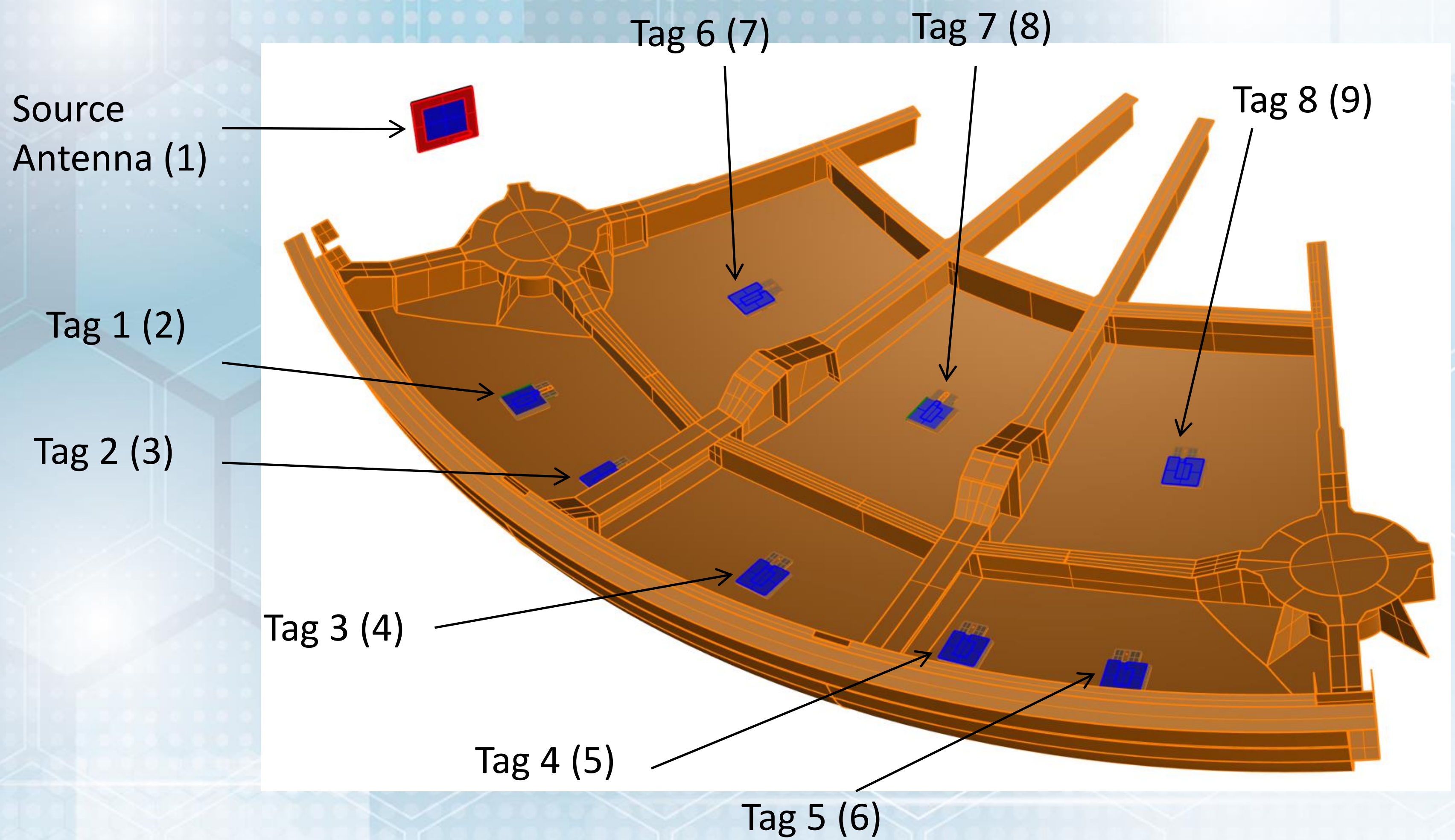


image source: nasa.gov

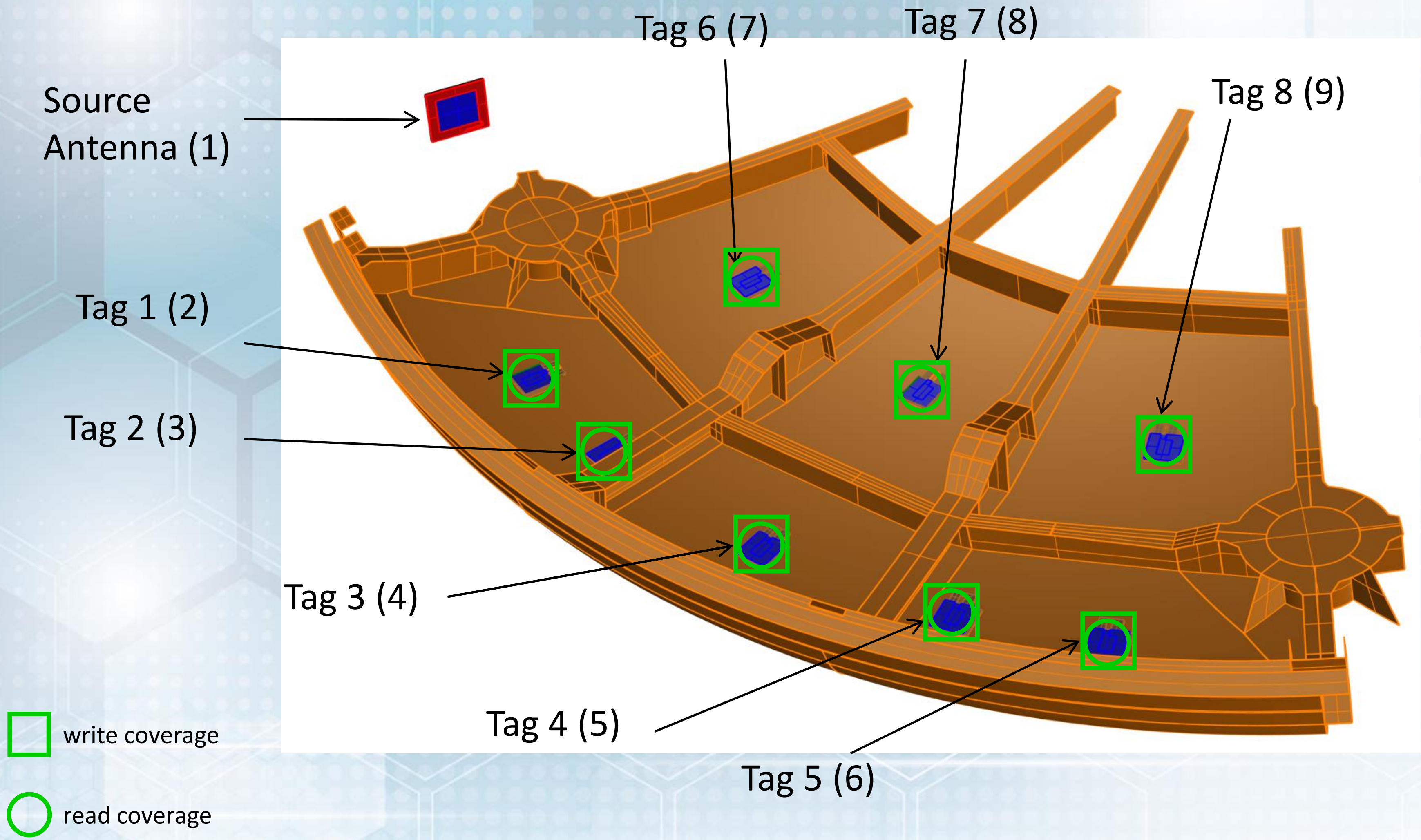
Sector E Heat Shield Modeling



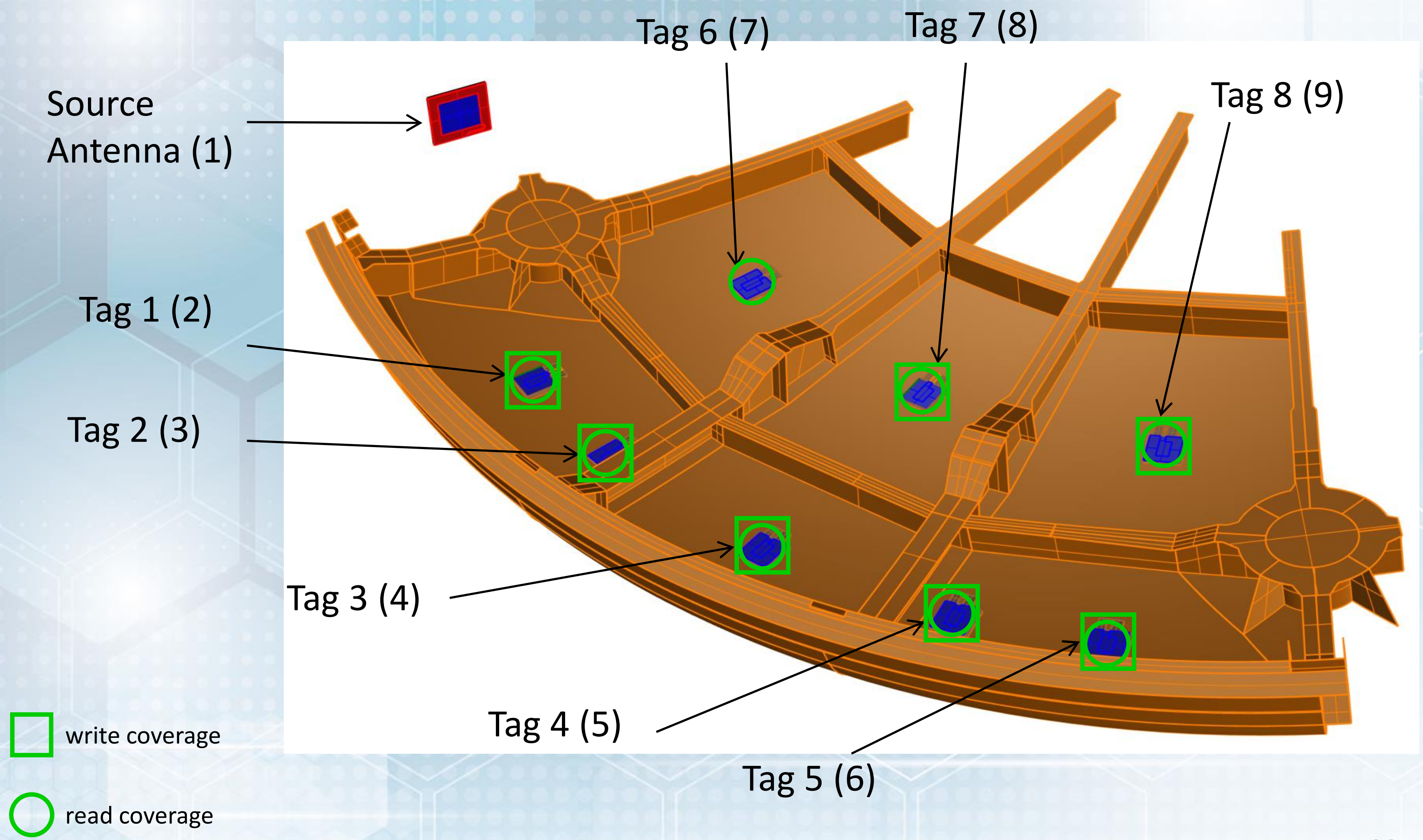
Sector E Heat Shield Modeling (cont.)



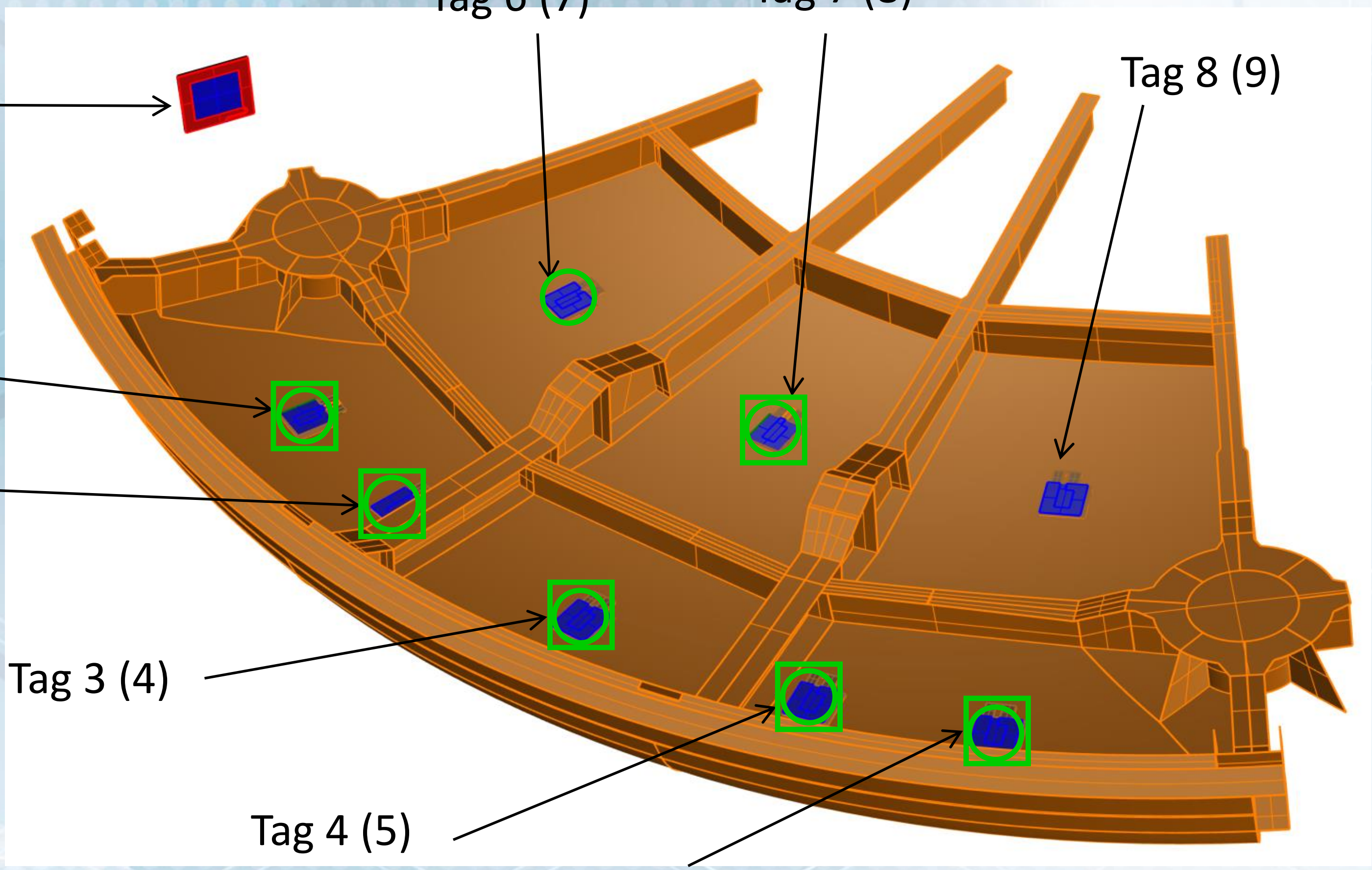
Sector E Heat Shield 1W Coverage



Sector E Heat Shield 100mW Coverage



Sector E Heat Shield 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

Conclusion
&
Next Steps

HDIAC Services

Technical Inquiry Service

- HDIAC provides up to 4 free hours of information services:
  - Literature searches
  - Document/bibliography requests
  - Analysis within our eight focus areas – Alternative Energy, Biometrics, CBRN Defense, Critical Infrastructure Protection, Cultural Studies, Homeland Defense and Security, Medical, Weapons of Mass Destruction

Core Analysis Task (CAT)

- Challenging technical problems requiring more than 4 hours of research can be solved by initiating a CAT:
  - Pre-competed and pre-awarded
  - Work can begin on a project approximately two months after the statement of work has been approved
  - Cap of $1,000,000 (on or after September 1, 2018)
  - Must be completed within 12 months

For more information: https://www.hdiac.org/technical-inquiries/

Thank You

Discussion, Questions, & Comments