A New Market for Terrestrial Single-Event Effects: Autonomous Vehicles

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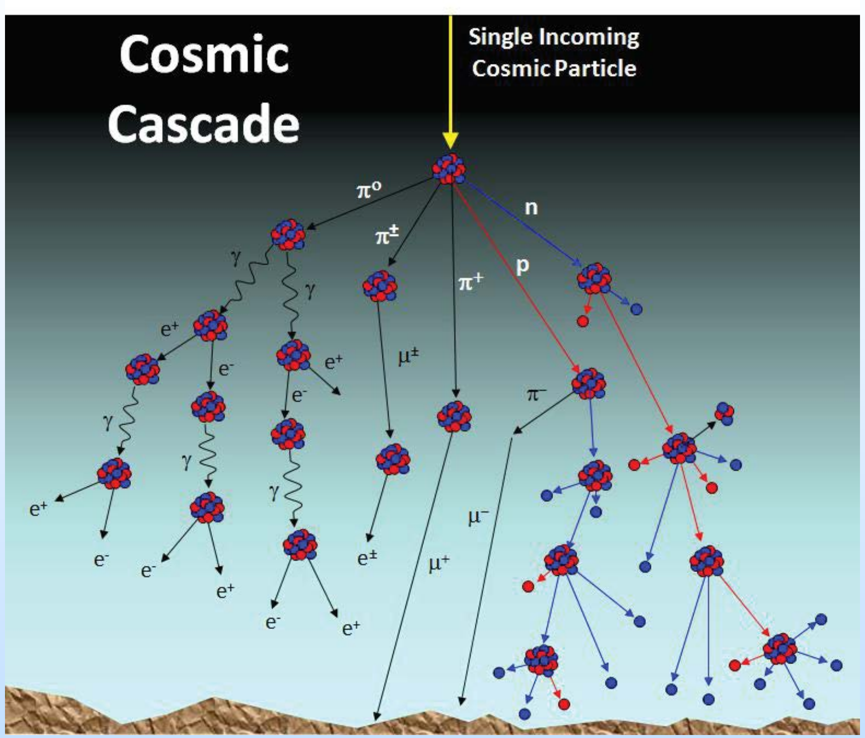
Acronyms

Abbreviation	Definition
ADAS	Advanced Driver-Assistance Systems
ASIL	Automotive Safety Integrity Level
COTS	Commerical-off-the-Shelf
ECSS	European Cooperation for Space Standardization
EN	European Norms
ESA	European Space Agency
ETW	(NEPP) Electronics Technology Workshop
FMEDA	Failure Modes, Effects, and Diagnostic Analysis
IC	Integrated Circuit
ICICDT	(IEEE) International Conference on IC Design and Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRPS	International Reliability Physics Symposium
ISO	International Organization for Standardization
MAPLD	Military and Aerospace Programmable Logic Devices (Workshop)
MBU	Multiple-Bit Upset
NASA	National Aeronautics and Space Administration
NEPP	NASA Electronic Parts and Packaging (Program)
NSREC	Nuclear and Space Radiation Effects Conference
PAS	Publicly Available Specification
SEB	Single-Event Burnout
SEE	Single-Event Effects
SEFI	Single-Event Functional Interrupt
SEGR	Single-Event Gate Rupture
SEL	Single-Event Latchup
SET	Single-Event Transient
SEU	Single-Event Upset
TNS	(IEEE) Transactions on Nuclear Science
VOD	Vehicle on Demand

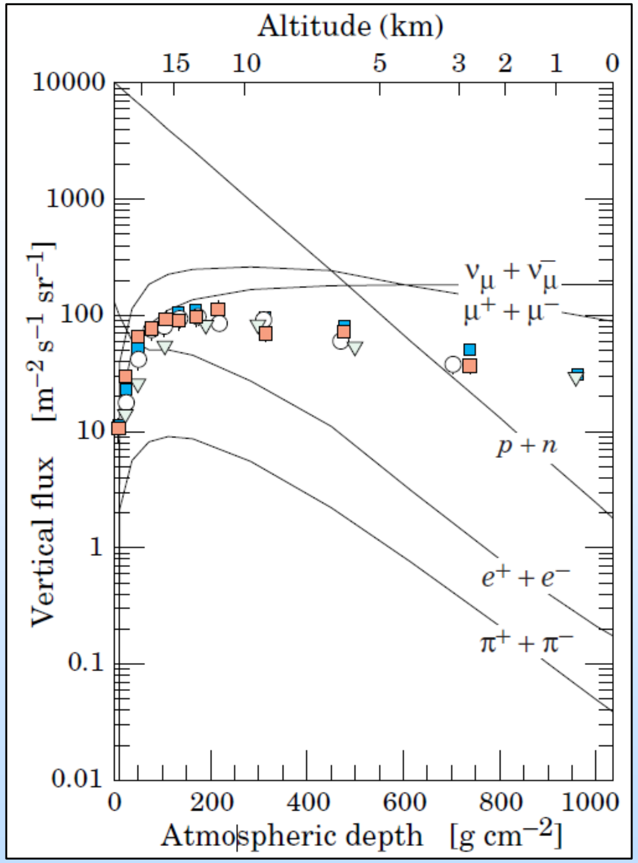
Overview

- Autonomous vehicle: cars, drones, trucks, etc.
  - Mostly focusing on vehicles today…
- Brief recap of alpha and neutron particle radiation at ground level
- Introduction to ISO-26262: *Road Vehicles – Functional Safety*
- Explore linkages between radiation hardness assurance for space systems and terrestrial autonomous systems – <u>it starts with COTS</u>
  - Destructive and non-destructive single-event effects
  - System failure rate assumptions
  - Validation and qualification tradeoffs; test challenges
  - Assurance: technology & design, system-level mitigation – how do I validate?
- C. Perrow, *Normal Accidents: Living with High-Risk Technologies*, Basic Books, 1984. (Cannot cover today, but suggested reading)
  - Detailed analysis of complex systems from a sociological perspective

Energetic Particles in Earth's Atmosphere

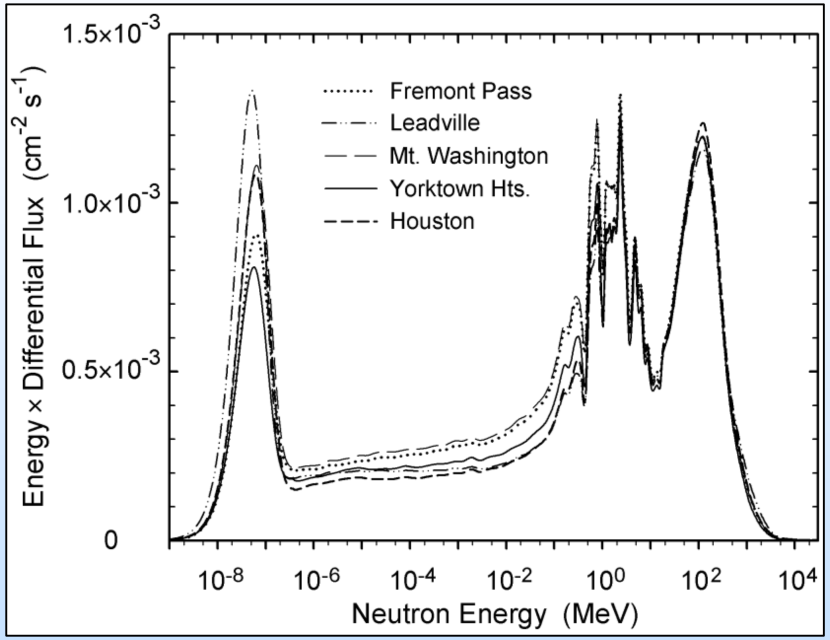


R. C. Baumann, *IEEE NSREC Short Course*, 2013.



M. Tanabashi *et al.*, (Particle Data Group), *Phys. Rev. D*, 98, 030001, 2018.

Measured neutron spectra. Each spectrum has been scaled to sea level at the cutoff of New York City and solar modulation for Nov. 2002



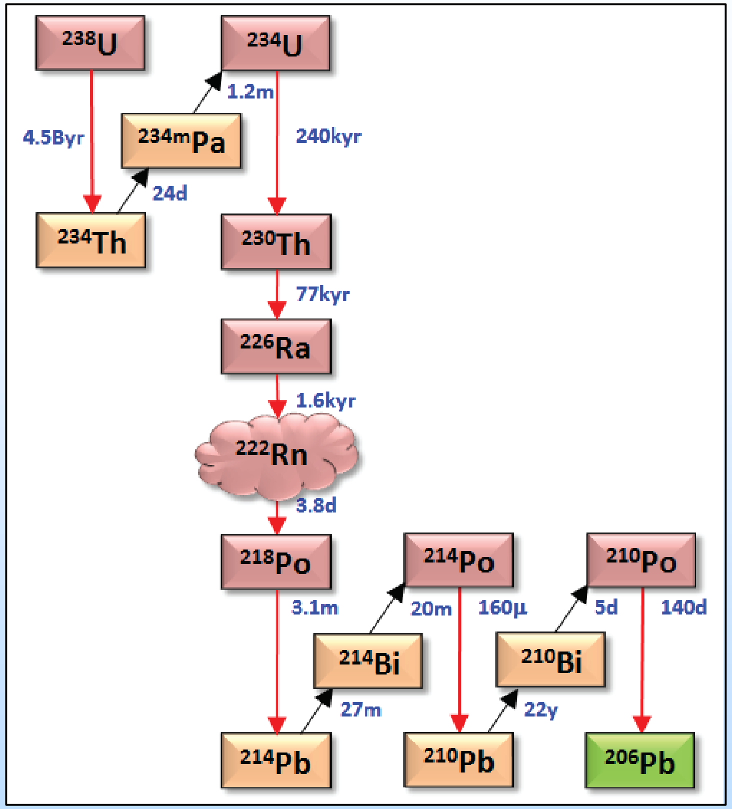
M. S. Gordon *et al.*, *IEEE Trans. Nucl. Sci.*, 2004.

- **High-energy particles impact Earth's atmosphere and create air showers that generate a variety of particles (e.g., neutrons etc.) that reach ground level – fluxes are anisotropic**
- **Depends on latitude/longitude, atmospheric depth, and solar activity**

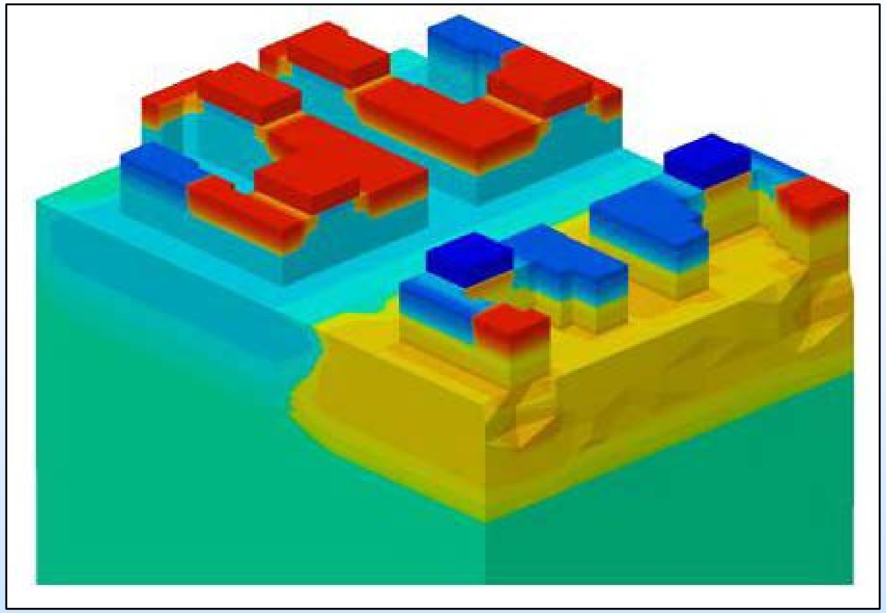
Energetic Particle Sources in the Parts Themselves

Alpha Particle (^{4}He) Radiation

Decay chain for ^{238}U



R. C. Baumann, *IEEE NSREC Short Course*, 2013.



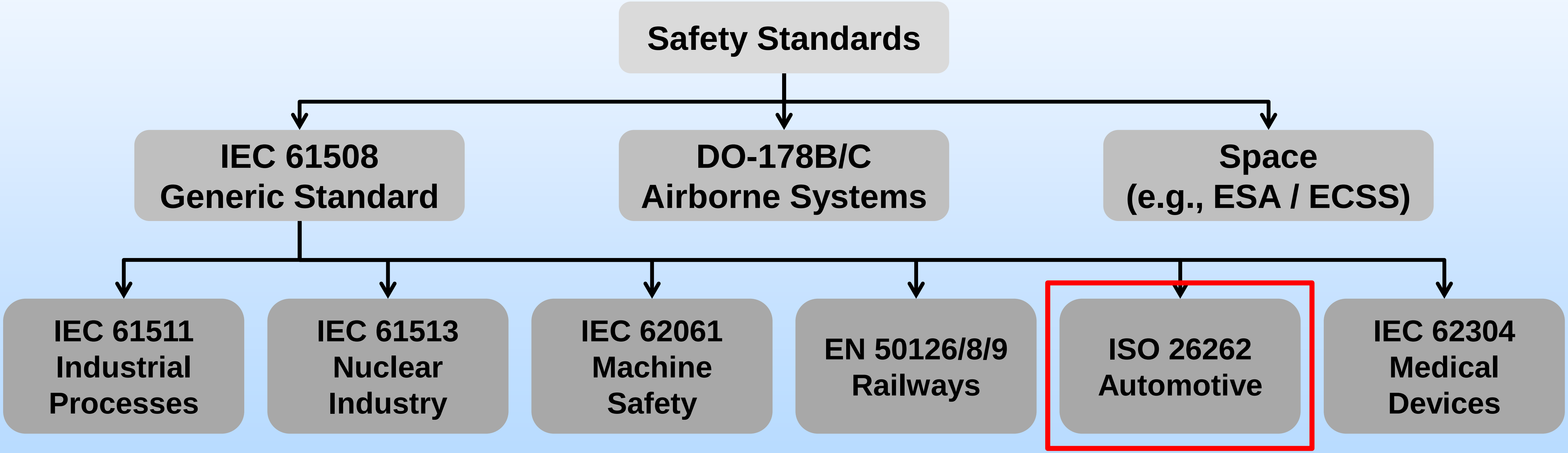
K. M. Warren *et al.*, *ICICDT* 2007.

- **Process contamination in wafer fab materials**
- **Trace elements in packaging**
- **Trace elements in metallic (e.g., Pb) bumps**

- **^{232}Th and ^{238}U are relatively abundant in terrestrial materials used in electronics processing and active enough to be a radiation effects concern**

ISO-26262: Road vehicles – Functional safety

ISO-26262 is part of the safety standards ontology



IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic (E/E/PE) Safety-related Systems

Adapted from S. Chung, ASSIC 2019, Santa Clara, CA, Apr. 2019

IEC 61508, ISO/PAS 19451 and ISO 26262

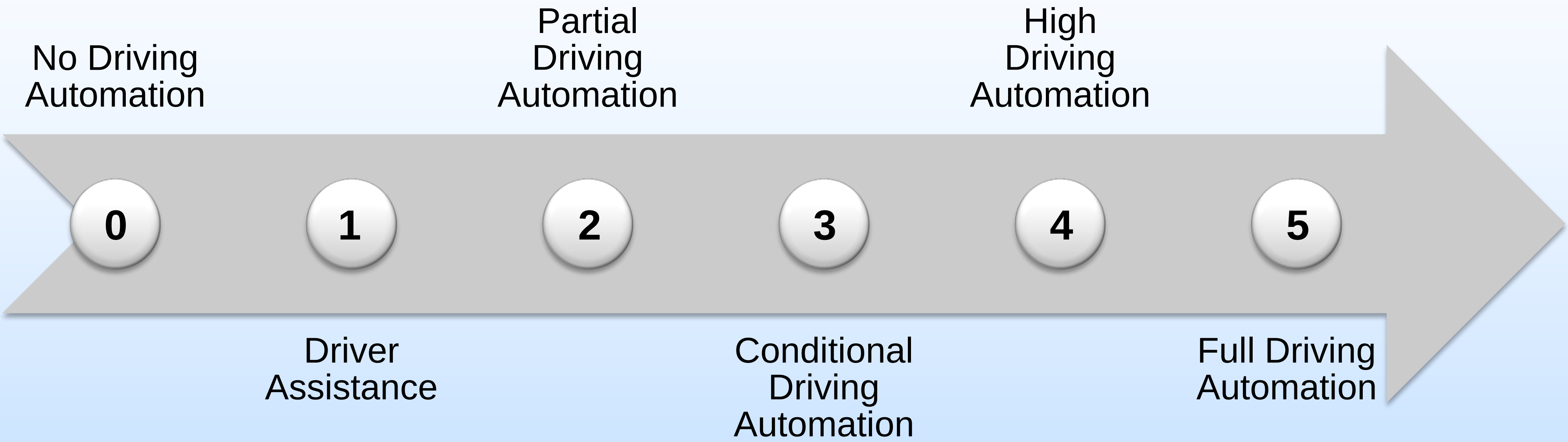
ISO-26262 revision released in December 2018

IEC 61508	ISO 26262
Part 1: General Requirements	**Part 1:** Vocabulary
Part 2: Requirements for Electrical / Electronic / Programmable Electronic Safety-Related Systems	**Part 2:** Management of Functional Safety
Part 3: Software Requirements	**Part 3:** Concept Phase
Part 4: Definitions and Abbreviations	**Part 4:** Product Development, System Level
Part 5: Examples of Methods for the Determination of Safety Integrity Levels	**Part 5:** Product Development, Hardware Level
Part 6: Guidelines on the Application of Parts 2 and 3	**Part 6:** Product Development, Software Level
Part 7: Overview of Techniques and Measures	**Part 7:** Production and Operation
	Part 8: Supporting Processes
	Part 9: ***Automotive Safety Integrity Level (ASIL)***-Orientated & Safety-Oriented Analyses
	Part 10: Guideline (on ISO 26262)
ISO/PAS 19451-1:2016	**Part 11:** Guidelines on Semiconductors

Adapted from S. Chung, ASSIC 2019, Santa Clara, CA, Apr. 2019

Climbing the Autonomy Ladder

Climbing the road vehicle autonomy ladder shares many parallels with what we want to do in space system design and operations

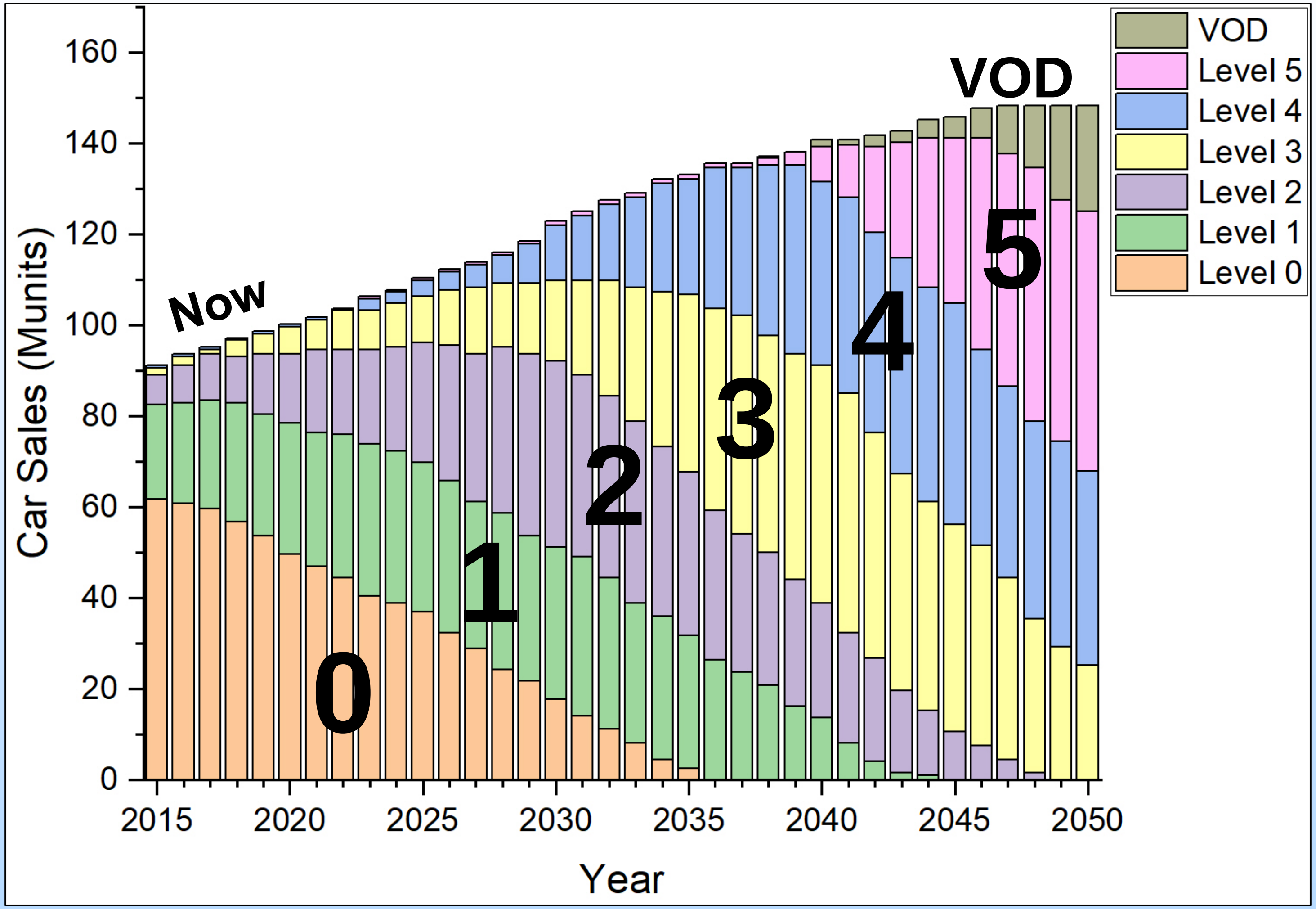


Adapted from SAE J3016, “Surface Vehicle Recommended Practice”

- **Climbing to Level 3+ requires massive computing power and levels of real-time ADAS integration that will necessitate a shift in testing and verification methodologies**
- **What will “adequate” state space coverage look like for a system guaranteed to experience random failures from radiation events?**
- **How well do we understand the technologies required to make this happen?**

Towards Fully Autonomous Vehicles

Potential Evolution of Autonomous Car Sales by Level of Automation

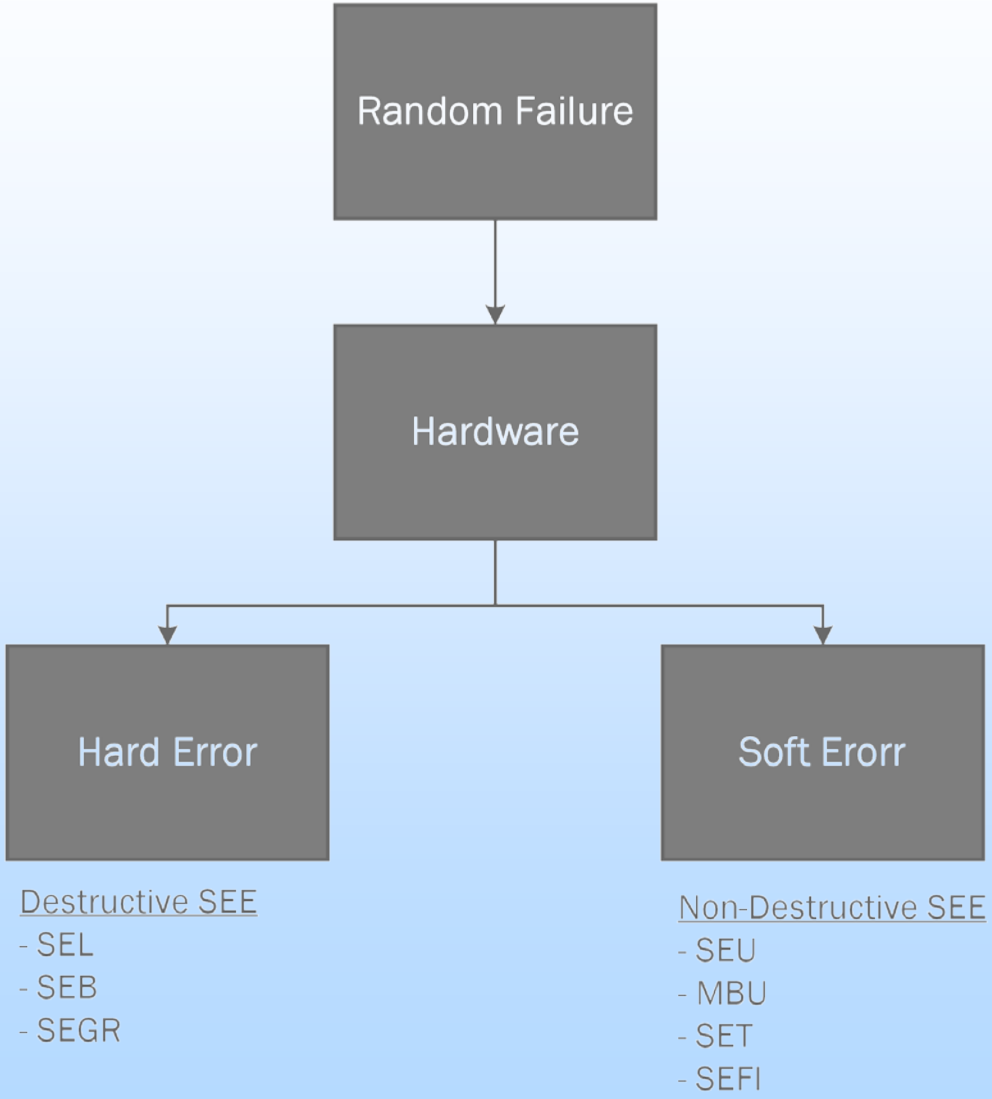


Feet Off Hands Off Eyes Off Mind Off

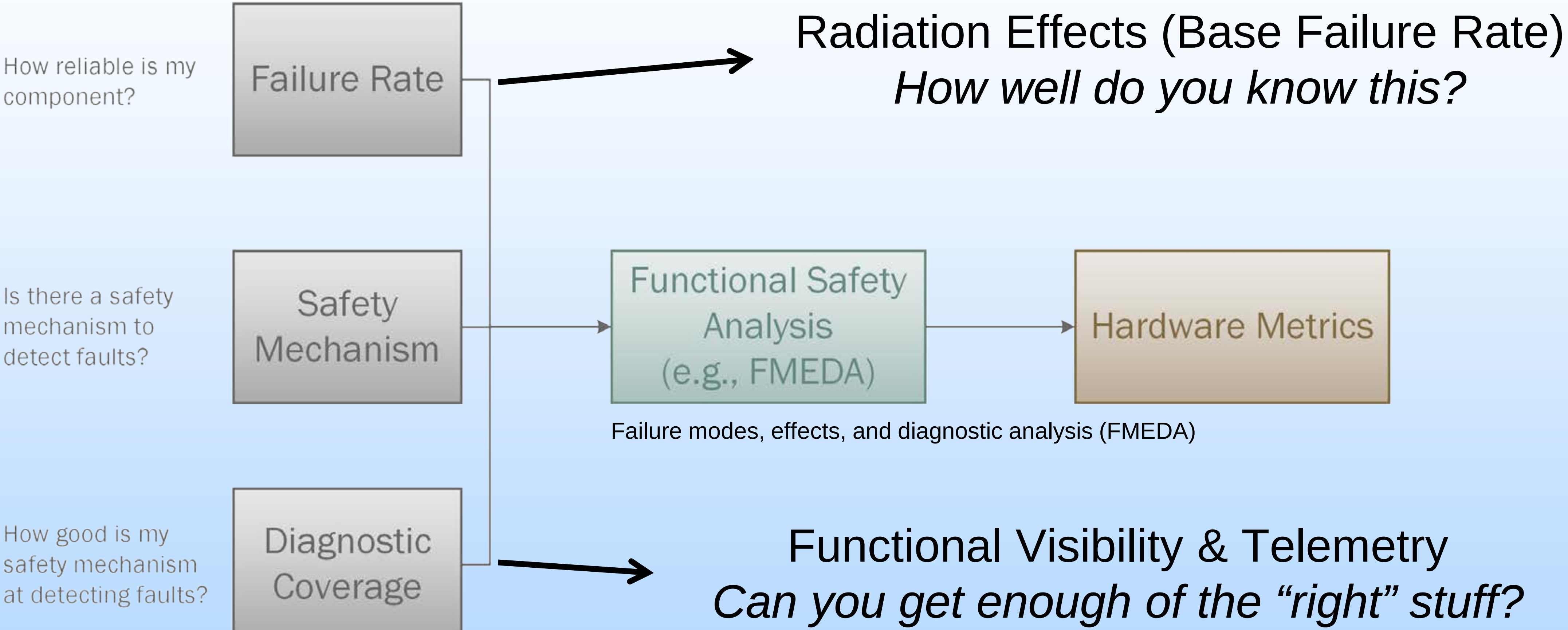
Adapted from: Smart Automotive–Latest Trends in LiDAR and Sensors, SEMICON, Dec. 2017.

Road Vehicle Functional Safety – Radiation Effects

- **Single-event effects (SEEs) show up as <u>random hardware failures</u>**
  - Stochastic failure that can occur during the lifetime of a component
  - Contribute to ***<u>base failure rate</u>***
- **SEEs follow a probability distribution that may or may not be known**
  - Constant with time, state-dependent, etc.
- **Can impact both availability and reliability**



Climbing the Autonomy Ladder – It Gets Harder



R. Kwasnick *et al.*, "Telemetry for reliability," *IEEE IRPS*, Monterey, CA, 2017, pp. 6C-2.1-6C-2.6.

Figure adapted from A. Keffer, "Functional Safety Verification," *SEE Symposium/MAPLD Workshop*, La Jolla, CA, May 2018.

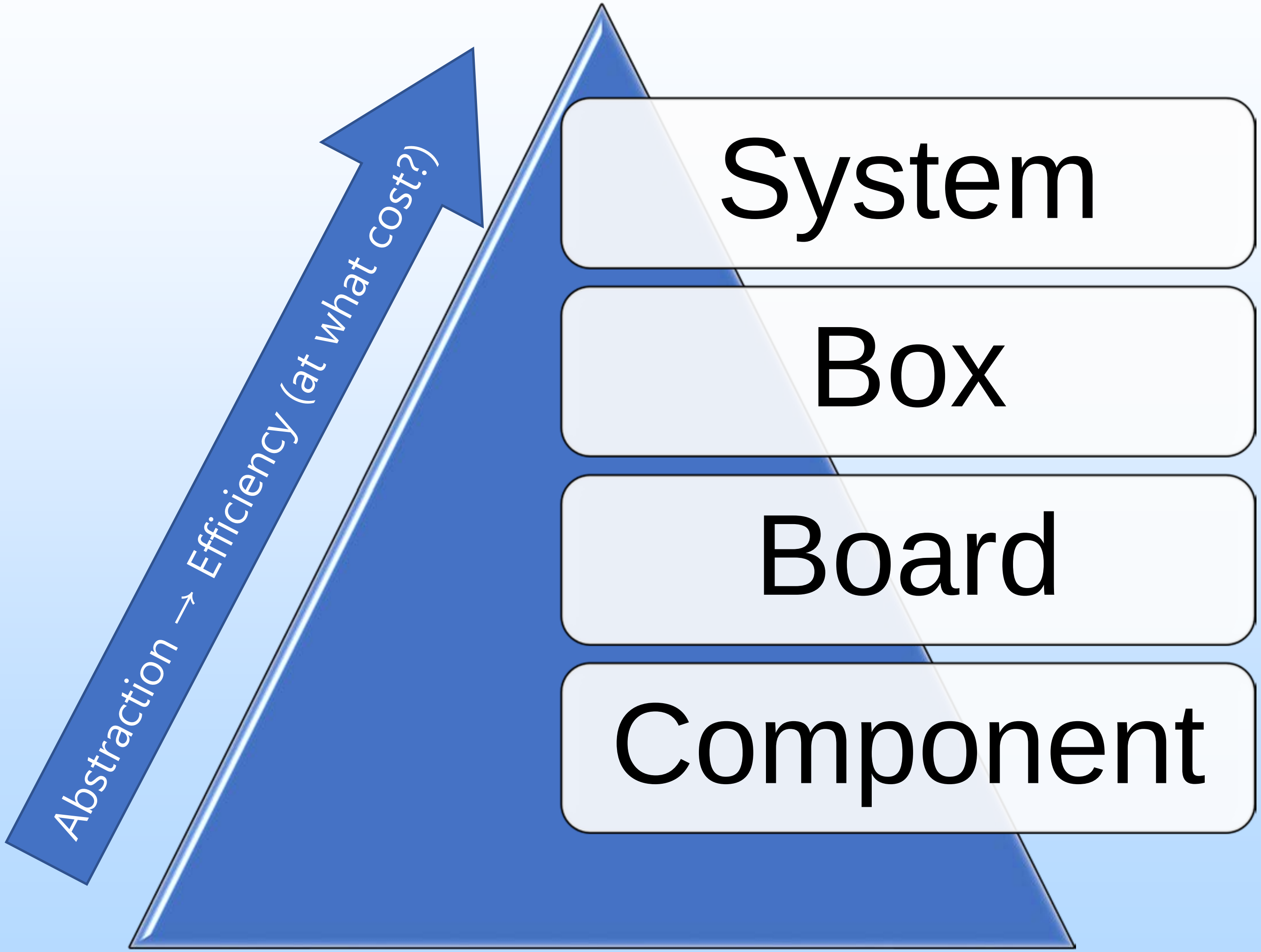
Reliability Prediction of Electronic Components
(ISO 26262-11:2018(E), Section 4.6)

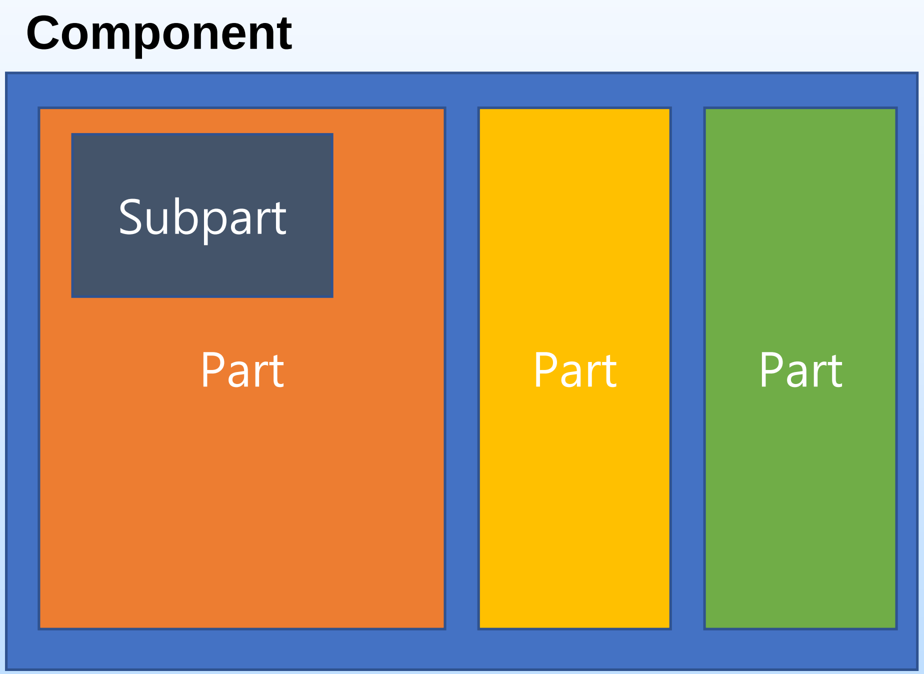
Some Rules of Thumb	Oops!
Latchup gets better with decreasing temperature	Latchup observed in read-out integrated circuit at cryogenic temperatures <40 K *(C. Marshall et al., TNS 2010)*
SEEs are not important for diodes	Schottky diodes observed to fail catastrophically due to previously unknown SEE mechanism *(R. Gigliuto and M. Casey, NEPP ETW 2012)*
If part has no tungsten plugs, no need to worry about proton destructive SEE if onset LET >20 MeV-cm^2/mg.	p+Au fission in packages with gold-plated plated lids produces ions w/ LET ~40 MeV-cm^2/mg *(T. Turflinger et al., TNS 2015)*

- **Estimating base failure rate assumes you understand the relevant failure modes – single-event effects (SEE) are random events, but can be systematic failures**
  - **Radiation hardness assurance evolves rapidly because its subject – semiconductor electronics – is constantly changing**
  - **Surprises found in testing about every 2 years or so; unknown unknowns**
- **Relying on assumptions based on experience is risky in a rapidly changing field**

Adapted from R. Ladbury, *IEEE NSREC Short Course*, July 2017.

Design Characterization & Qualification Trade Space



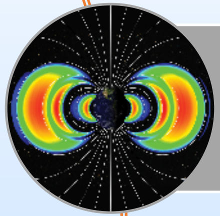


Based on ISO 26262-11:2018(E) Fig. 2

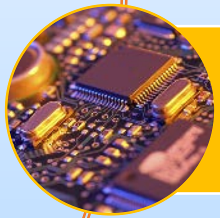
Radiation Assurance Requires Synchronous Integration

This is why radiation engineers tend to answer with "it depends…"

Mission



Environment



Application

Lifetime

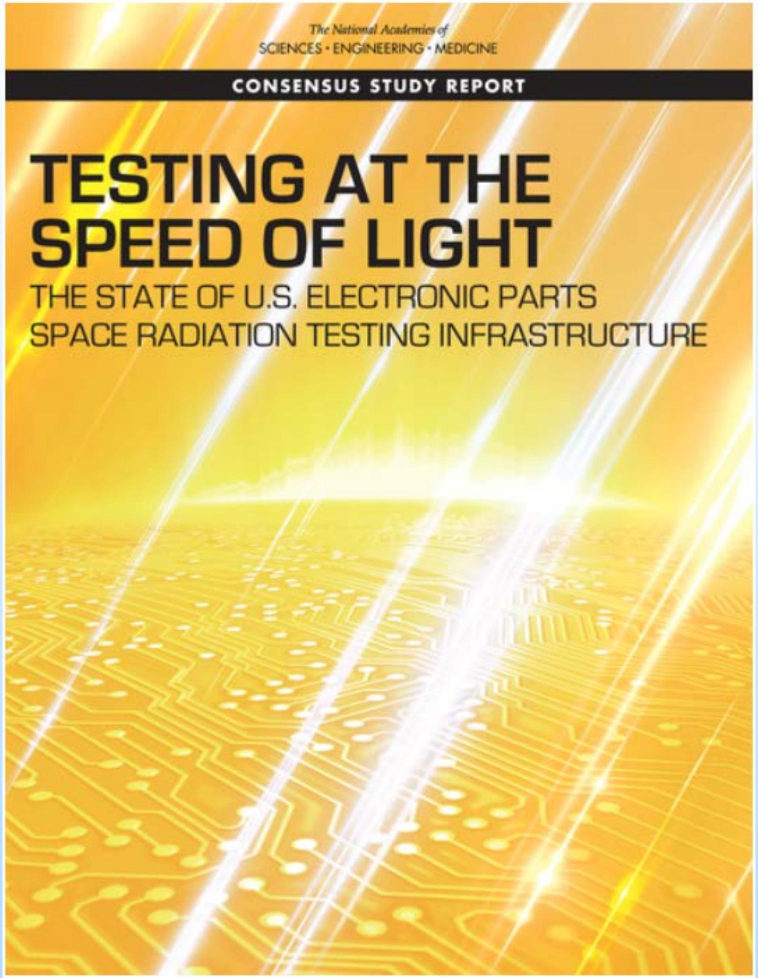
- Considerations summarized in these elements allow designers to effectively choose parts for their best performance in a given architecture
- Comprehension requires a complete synchronous picture of how technologies are to be used effectively
- Emphasizing one of these elements without understanding the others can compromise the integrity and performance of the parts and mission success

Image credits: NASA and other government sources

Adapted from NASA Technical Report TM-2018-220074

Test Facilities – State of the Practice *(for Space)*

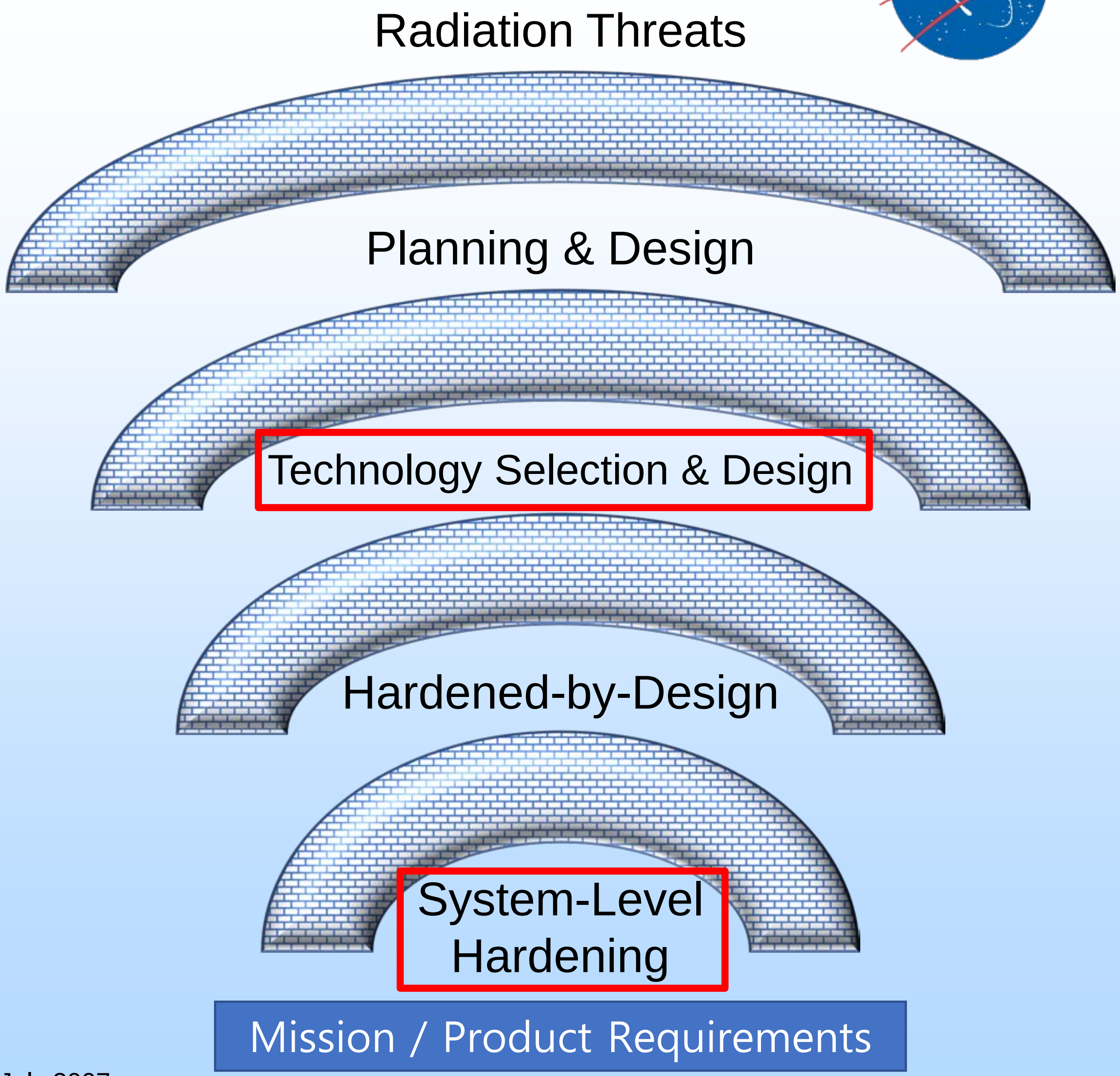
- **Even with sophisticated modeling, radiation testing remains essential to characterize, qualify, and validate**
- **While targeted at space community, growing overlap for other high-reliability electronics / systems markets (e.g., accelerated *n* & *p*+)**
- **Generally, a small number of test facilities service radiation effects test needs – we tend to be parasitic users**
  - **In U.S., continued partnering with medical therapy community for high-energy protons**
  - **For high-energy neutrons, facility count is small**
- **Report lays out plans for necessary facility upgrades and discusses workforce challenges**
  - **Probably going to get tougher before it gets easier**



https://doi.org/10.17226/24993
Issued 2018

System-Level Assurance
(Space Users Perspective)

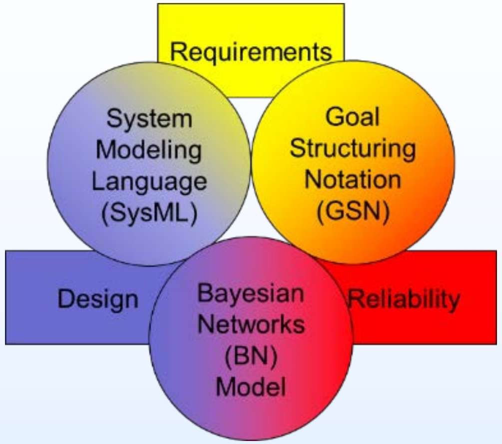
- **Always faced with conflicting demands between**
  - **"Just Make It Work," and**
  - **"Just Make It Cheap"**
- **Many system-level mitigation strategies pre-date the space age (e.g., communications, fault-tolerant computing, etc.)**
- **Tiered approach to validation of mission / product requirements**



R. Ladbury, *IEEE NSREC Short Course*, July 2007.

Summary Thoughts

- **Remember that space radiation, and modulation due to space weather, affects the terrestrial radiation environment – alpha particles are an additional environment**
- **Acknowledge that in large-scale systems (of systems), radiation effects can have both technical and societal impacts**
- **Invoke a tiered approach for radiation effects assurance and maintain awareness that there are unknown unknowns due to rapid technology evolution**
- **Explore additional synergies with the broader autonomous vehicle communities – we're grappling with the same challenges as more advanced technologies enter our systems (e.g., reliability, availability, supply chain, etc.)**



Emerging Assurance Methods
(Witulski, Vanderbilt University, NEPP ETW 2017)

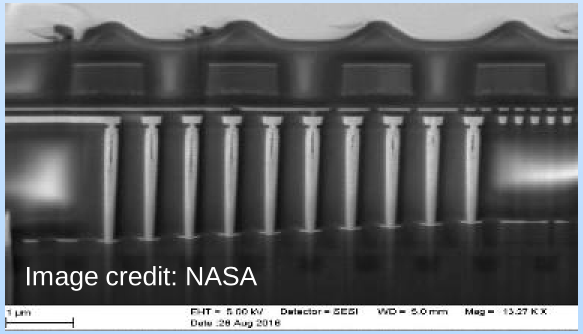
Image credit: Vanderbilt / NASA

10th Annual NEPP Electronics Technology Workshop

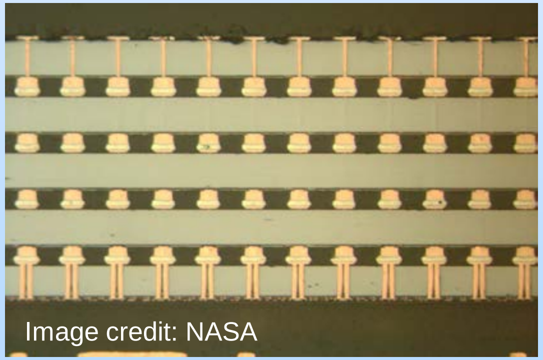
Radiation Testing

Scheduled dates:

Week of June 17, 2019
NASA/GSFC and on-line



Advanced Technology Reliability



Commercial IC Packaging

https://nepp.nasa.gov/

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