The NASA Electronic Parts and Packaging (NEPP) Program: Roadmap for FY15 and Beyond and Recent Radiation Highlights

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Outline

- **NEPP Task and Technology Selection**
  - **Background**
  - **Task Roadmaps**
  - **Other Cool Tasks**
- **Radiation Highlights**
  - **Proton Facility Status**
  - **INTEL 14nm Processors**
- **Summary**

Sundown at SCRIPPS Proton Therapy Center, Ken LaBel

Acronyms

Acronym	Definition
3D	Three Dimensional
ADC	analog-to-digital converter
AES	Advanced Encryption Standard
AF SMC	Air Force Space & Missile Systems Center
AFRL	Air Force Research Laboratory
AMOLED	Active Matrix Organic Light Emitting Diode
AMS	Agile Mixed Signal
ARM	ARM Holdings Public Limited Company
CAN	Controller Area Network
CAN-FD	Controller Area Network Flexible Data-Rate
CBRAM	Conductive Bridging Random Access Memory
CCI	Correct Coding Initiative
CGA	Column Grid Array
CIGS	Copper Indium Gallium Selenide
CMOS	Complementary Metal Oxide Semiconductor
COTS	Commercial Off The Shelf
CPU	Computer Processing Unit
CRC	Cyclic Redundancy Check
CREME	Cosmic Ray Effects on Micro-Electronics
CSE	Computer Science and Engineering
CU	Cu alloy
D-Cache	Data Cache
DCU	Display Controller Unit
DDR	Double Data Rate
DDR2	Double Data Rate Two
DDR3	Double Data Rate Three
DDR4	Double Data Rate Four
DMA	Direct Memory Access
DNA	Deoxyribonucleic Acid
DoD	Department of Defense
DRAM	Dynamic Random Access Memory
DSP	Digital Signal Processing
dSPI	Dynamic Signal Processing Instrument
DTRA	Defense Threat Reduction Agency
Dual Ch	Dual Channel
ECC	Error-Correcting Code
EEE	Electrical, Electronic, and Electromechanical
EMAC	Equipment Monitor And Control
EPC	Efficient Power Conversion
ESL	Electronic System Level
eTimers	Event Timers
FCCU	Fluidized Catalytic Cracking Unit
FeRAM	Ferroelectric RAM
FinFET	Fin Field Effect Transistor (the conducting channel is wrapped by a thin silicon "fin")

Acronym	Definition
FlexRay	FlexRay communications bus
FPGA	Field Programmable Gate Array
FY	Fiscal Year
GaN	Gallium Nitride
Gb/s	gigabyte per second
Gen	Generation
GIC	Global Industry Classification
GPU	Graphics Processing Unit
GSFC	Goddard Space Flight Center
HALT	Highly Accelerated Life Test
HAST	Highly Accelerated Stress Testing
HDIO	High Density Digital Input/Output
HDR	High-Dynamic-Range
HEMTs	High-electron-mobility transistors
HP Labs	Hewlett-Packard Laboratories
HPIO	High Performance Input/Output
HUPTI	Hampton University Proton Therapy Institute
HW	Hardware
I2C	Inter-Integrated Circuit
IBM	International Business Machines
IBM/GF	International Business Machines/GlobalFoundaries
IC	Integrated Circuit
I-Cache	Instruction Cache
IoT	Internet of Things
IP	Intellectual Property
IR	Infrared
IR/Infineon	International Rectifier/Infineon Technologies
IUCF	Indiana University Cyclotron Facility
JPEG	Joint Photographic Experts Group
KB	Kilobyte
L2 Cache	independent caches organized as a hierarchy (L1, L2, etc.)
LCoS	Liquid-Crystal-on-Silicon
LET	linear energy transfer
LinFlex	Local Interconnect Network Flexible
LLUMC	Slater Proton Treatment and Research Center at Loma Linda University Medical Center
L-mem	Long-Memory
LP	Low Power
M/L BIST	Memory/Logic Built-In Self-Test
MBSE	Model-Based Systems Engineering
MEMS	Micro Electrical-Mechanical System
MGH	Mass General Francis H. Burr Proton Therapy
MIPI	Mobile Industry Processor Interface
MOSFETS	Metal Oxide Semiconductor Field Effect Transistors
MPSoC	Multi-Processor System on a Chip
MRAM	Magnetoresistive Random Access Memory
Msg	Message

Acronym	Definition
NASA	National Aeronautics and Space Administration
NAVY Crane	Naval Surface Warfare Center, Crane, Indiana
NEPP	NASA Electronic Parts and Packaging
NGSP	Next Generation Space Processor
NOR	Not OR logic gate
NSRL	NASA Space Radiation Lab
Occam	Open Conditional Content Access Management
OKC	Oklahoma City
OLED	Organic Light Emitting Diode
PBGA	Plastic Ball Grid Array
PCIe	Peripheral Component Interconnect Express
PCIe Gen2	Peripheral Component Interconnect Express Generation 2
PCIe Gen4	Peripheral Component Interconnect Express Generation 4
PS-GTR	Global Regulation on Pedestrian Safety
R&D	Research and Development
RAM	Random Access Memory
ReRAM	Resistive Random Access Memory
RF	Radio Frequency
RGB	Red, Green, and Blue
RH	RAD-Hard
SAR	Successive-Approximation-Register
SATA	Serial Advanced Technology Attachment
SCU	Secondary Control Unit
SD/eMMC	Secure Digital embedded MultiMediaCard
SD-HC	Secure Digital High Capacity
SDRAM	Synchronous Dynamic Random Access Memory
SEE	Single Event Effect
SERDES	Serializer/Deserializer
SiC	Silicon Carbide
SMMU	System Memory Management Unit
SOC	System on a chip
SPI	Serial Peripheral Interface
SPU	Synergistic Processor Unit
TCM	Tightly Coupled Memory
TI	Texas Instruments
TRIUMF	Tri-University Meson Facility
TRL	Technology Readiness Level
T-Sensor	Temperature-Sensor
TSMC	Taiwan Semiconductor Manufacturing Company
UART	Universal Asynchronous Receiver/Transmitter
UFHPTI	University of Florida Health Proton Therapy Institute
USB	Universal Serial Bus
VNAND	Vertical NAND
WBG	Wide Band Gap
WDT	Watchdog Timer

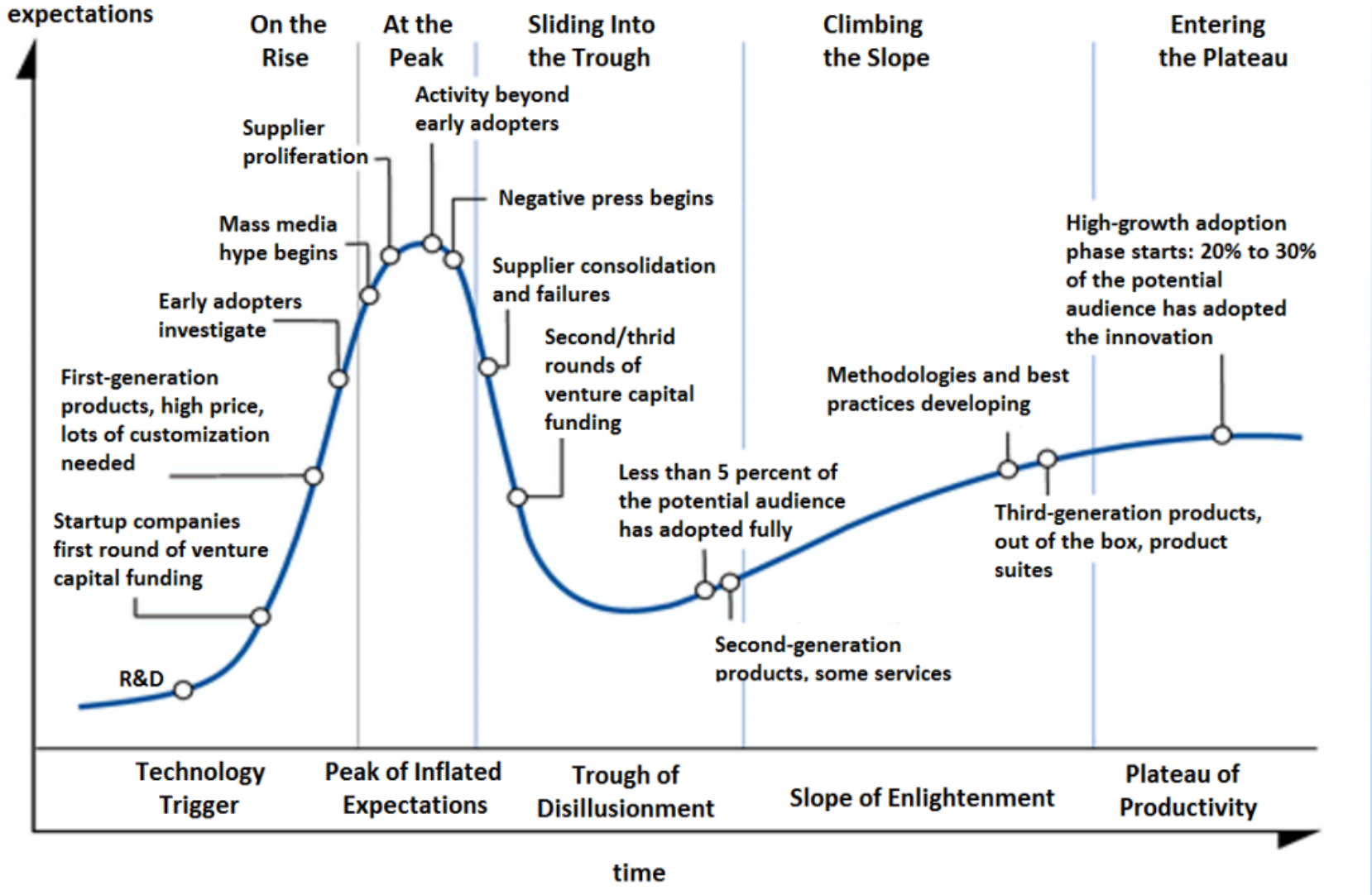
Technology Selection Criteria for NEPP Investigation

- **The technologies should satisfy all or most of the following criteria:**
  - **Wide applicability,**
  - **Product level or in productization, and,**
  - **No distinction: COTS to hi-reliability aerospace.**
- **In general, we avoid:**
  - **Laboratory technologies, e.g., <TRL3,**
  - **Limited application devices with certain exceptions (critical application or NASA center specialization).**
- **Note: Partnering arrangements with other organizations preferred.**
  - **Industry examples: Microsemi, Xilinx, Altera, TI**
  - **Other U.S. Government: AF SMC, AFRL, DTRA, Navy Crane**

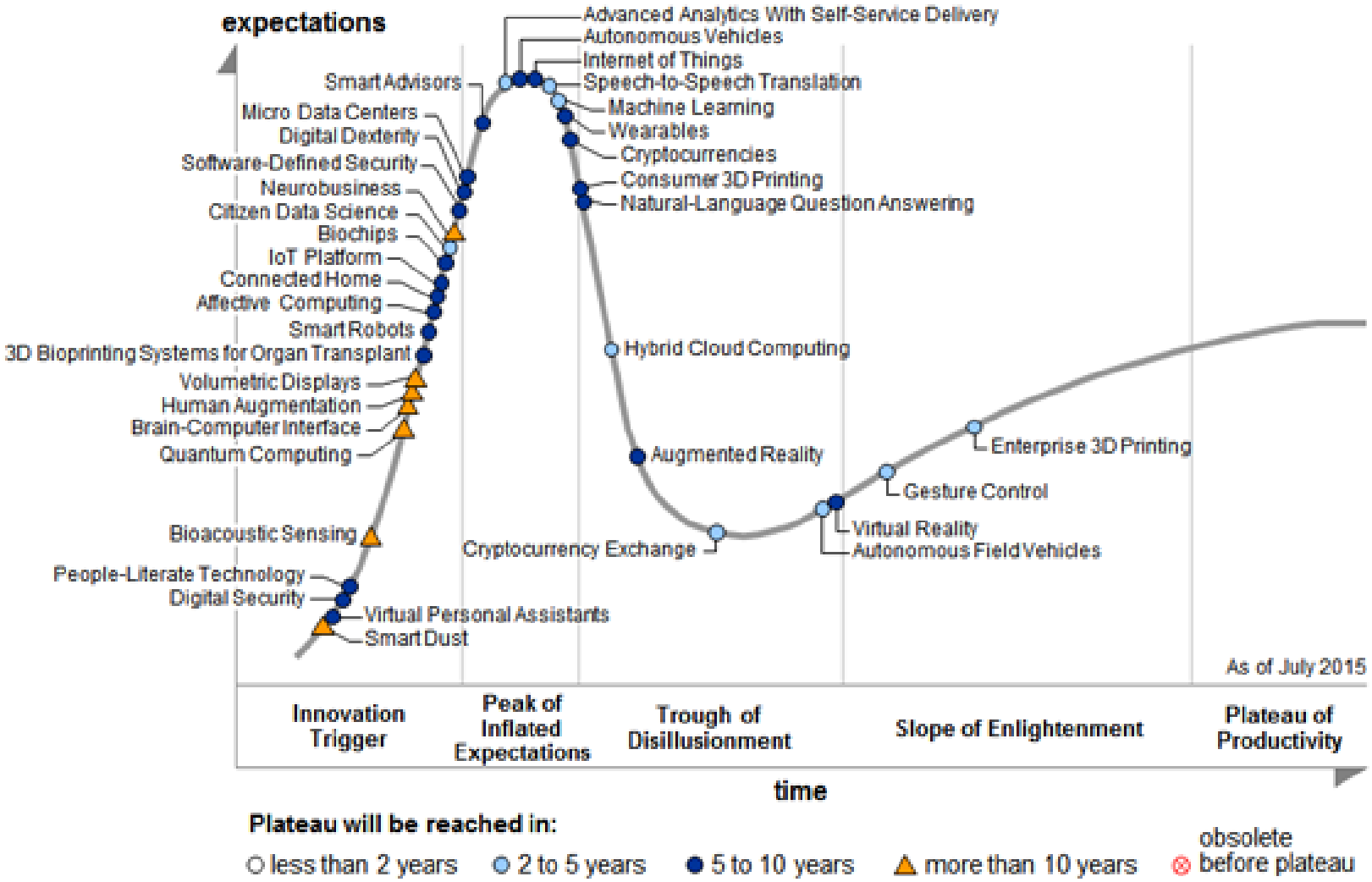
Technology Investigation Roadmap Discussion

- **Technology assurance efforts are not explicitly included except on "Small Missions" chart.**
  - ***Guidelines are a product of many technology evaluation tasks.***
- **Only major product categories shown.**
- **Technology areas not on Roadmap but under consideration include:**
  - **Electro-optics (fiber optics),**
  - **Advanced analog and mixed-signal devices,**
  - **Imaging sensors,**
  - **Modeling and simulation,**
  - **High-speed communication (SERDES, fast data switches), and,**
  - **Adjunct processors (eg., graphics, signal processing)**
- **Note 1: Advanced CMOS technologies not explicitly included:**
  - **NEPP leverages samples from ongoing DoD and/or commercial sources.**
  - **14nm is current target (IBM/GF, INTEL).**
- **Note 2: "Reliability testing" may include product and/or package testing.**

Gartner Hype Cycle Concept

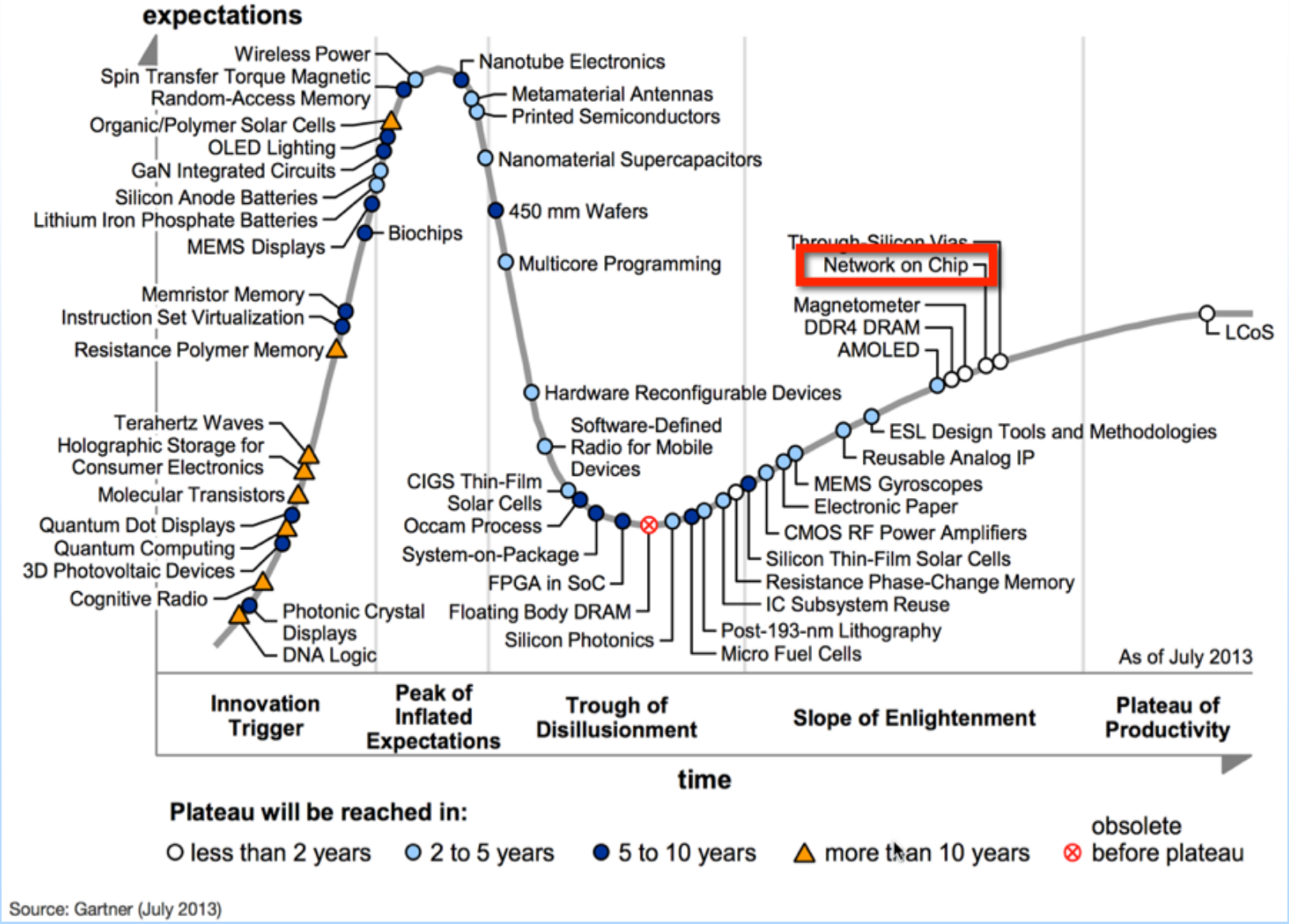


Gartner Hype Cycle for Emerging Technologies 2015



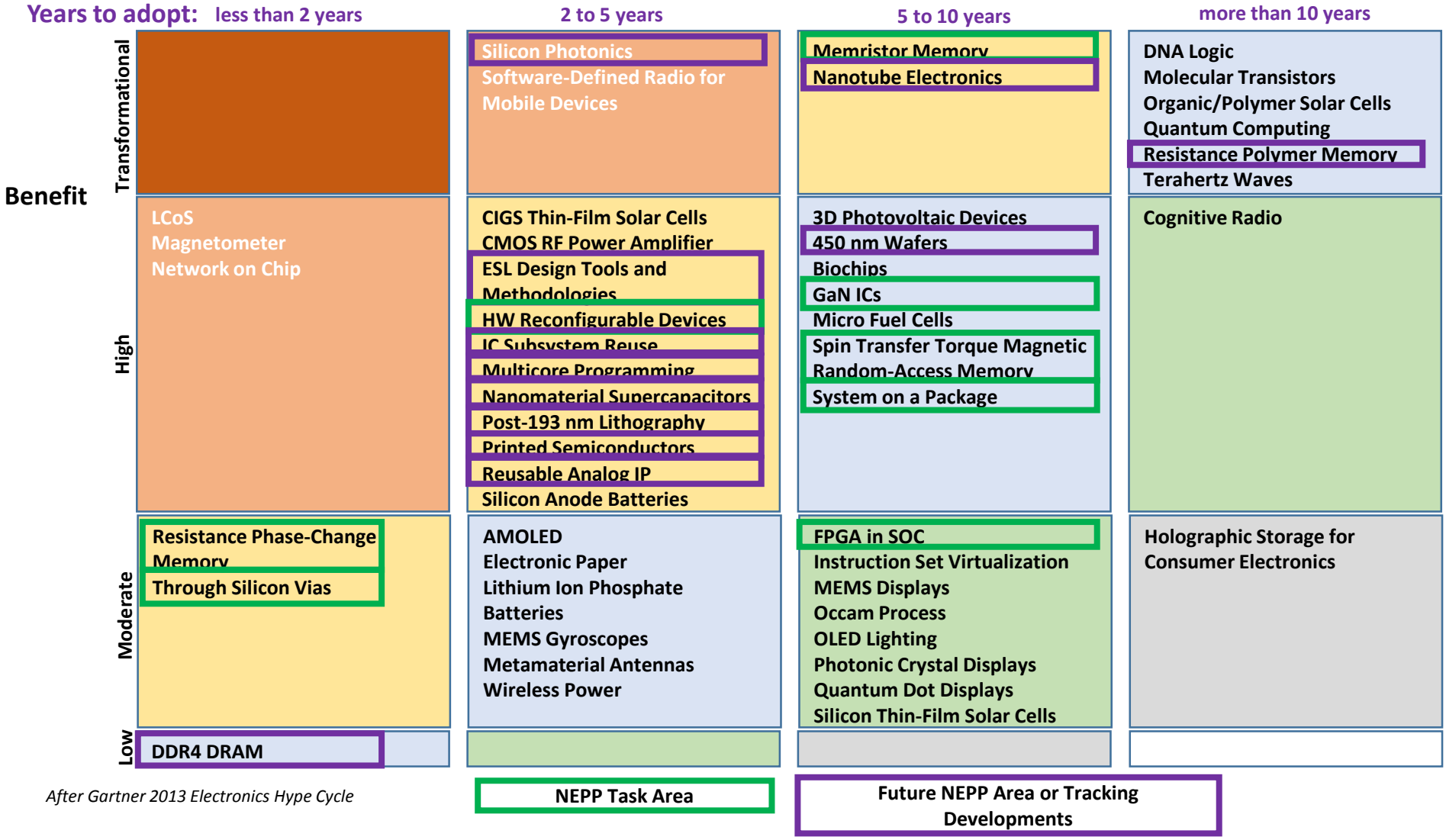
http://www.gartner.com/newsroom/id/3114217

Gartner Hype Cycle for Electronics 2013



Source: Gartner (July 2013)

NEPP and Gartner Electronics Hype Cycle 2013



Field Programmable Gate Arrays (FPGAs)

Trusted FPGA

- **DoD Development**

Altera

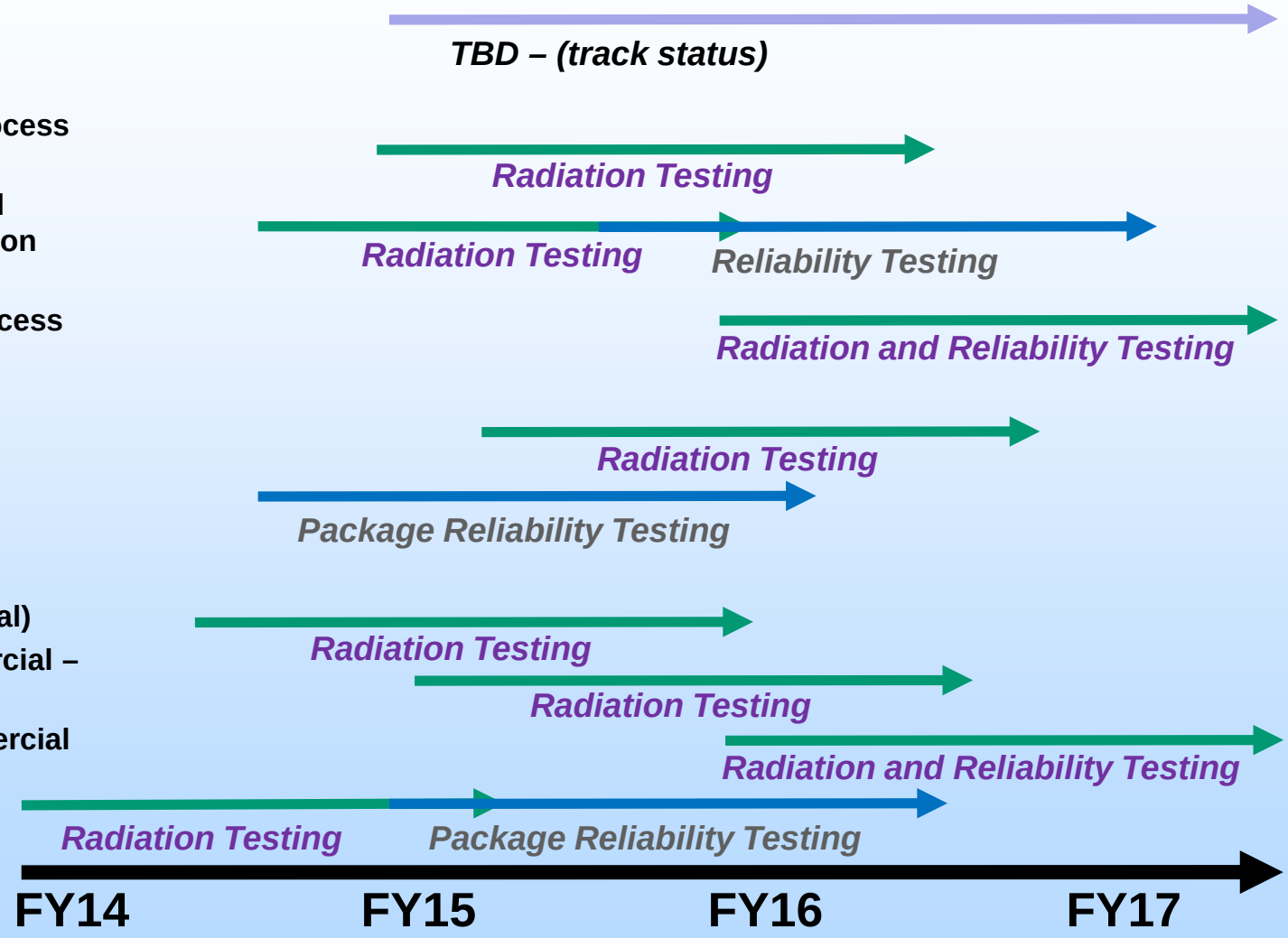
- **Stratix 5 (28nm TSMC process commercial)**
- **Max 10 (55nm NOR based commercial – small mission candidate)**
- **Stratix 10 (14nm Intel process commercial)**

Microsemi

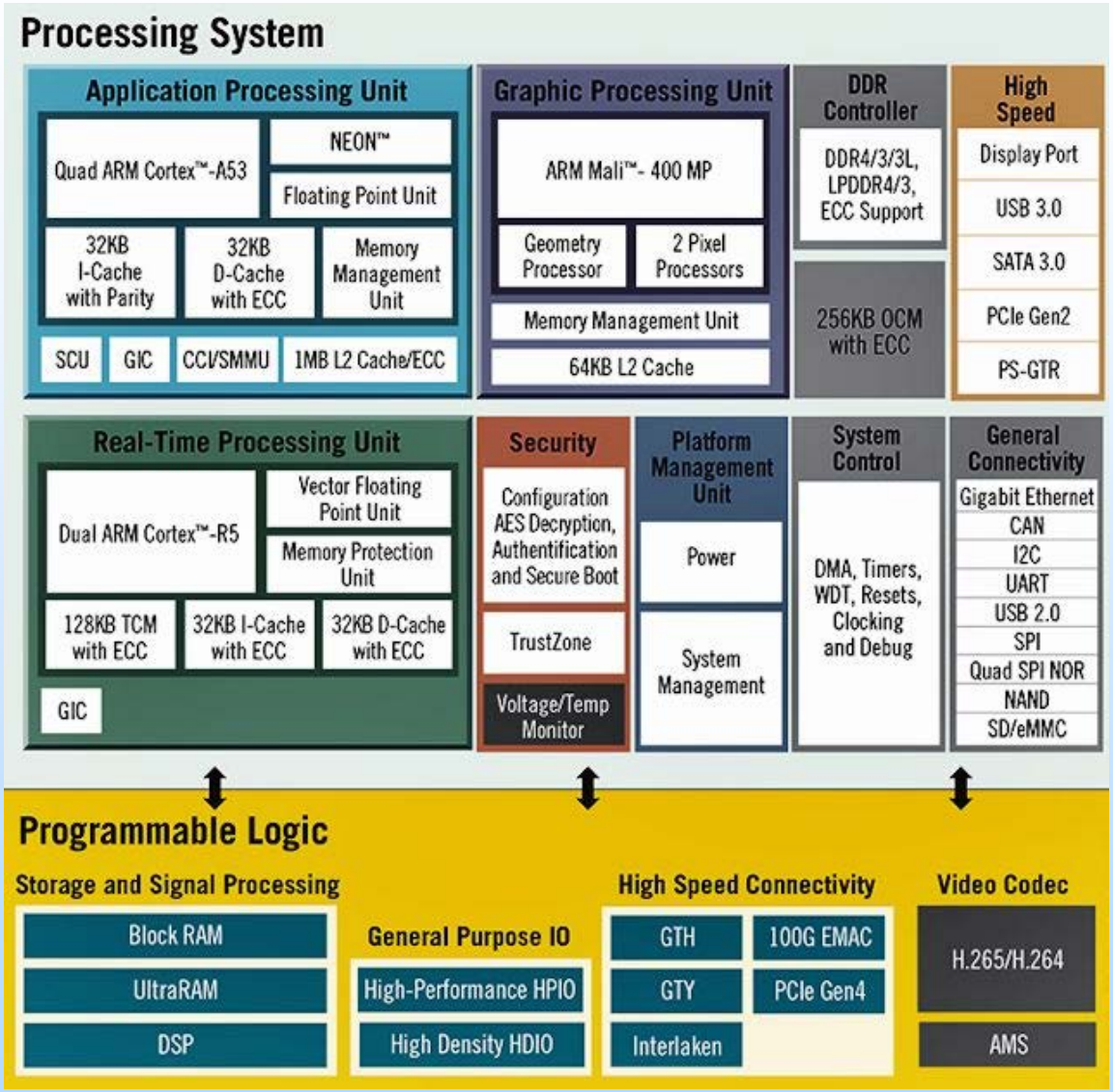
- **RTG4 (65nm RH)**

Xilinx

- **7 series (28nm commercial)**
- **Ultrascale (20nm commercial – planar)**
- **Ultrascale+ (16nm commercial - vertical)**
- **Virtex 5QV (65nm RH)**



Xilinx Zynq UltraScale+ Multi-Processor System on a Chip (MPSoC) family



From Xilinx.com

Advanced Processors

Next Generation Space Processor (NGSP)

- Joint NASA-AFRL Program for RH multi-core processor
- TBD architecture/process

TBD – (track status)

RH Processor

- BAE Systems RAD5510/5545
- Replacement for RAD750

Radiation Testing

Intel Processors (w/Navy Crane)

- 14nm FinFET commercial (5th and 6th generation)
- 5th generation is 1st high-performance sans heatsink (lower power for performance)

Reliability Testing

Radiation Testing

Freescale P5020/5040

- Commercial 45nm network processor
- Preparation for RH processor

Reliability Testing

Radiation Testing

FY14 FY15 FY16 FY17

Note: Future considerations under discussion include automotive "self-driving" processor options.

Microcontrollers and Mobile Processors (Small Missions)

TBD – other

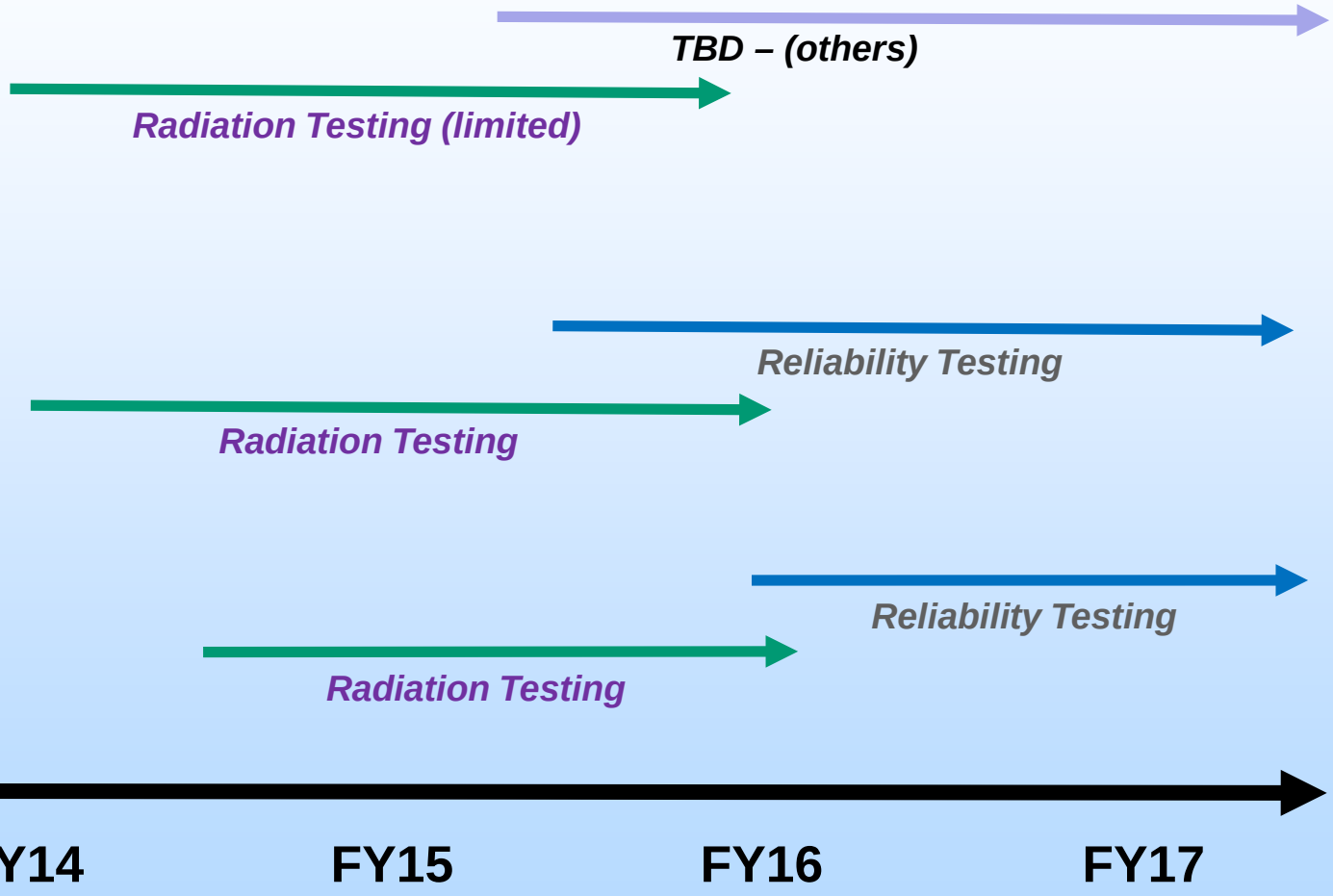
- Atmel AT91SAM9G20, and TI Sitara AM3703,
- ARM (Snapdragon), Intel Atom mobile

TI MSP430

- Popular CubeSat microcontroller
- Several varieties

Freescale MPC56XX

- 90nm on-shore fab
- Automotive Grade
- Being used for both part and board level testing



Commercial Memory Technology

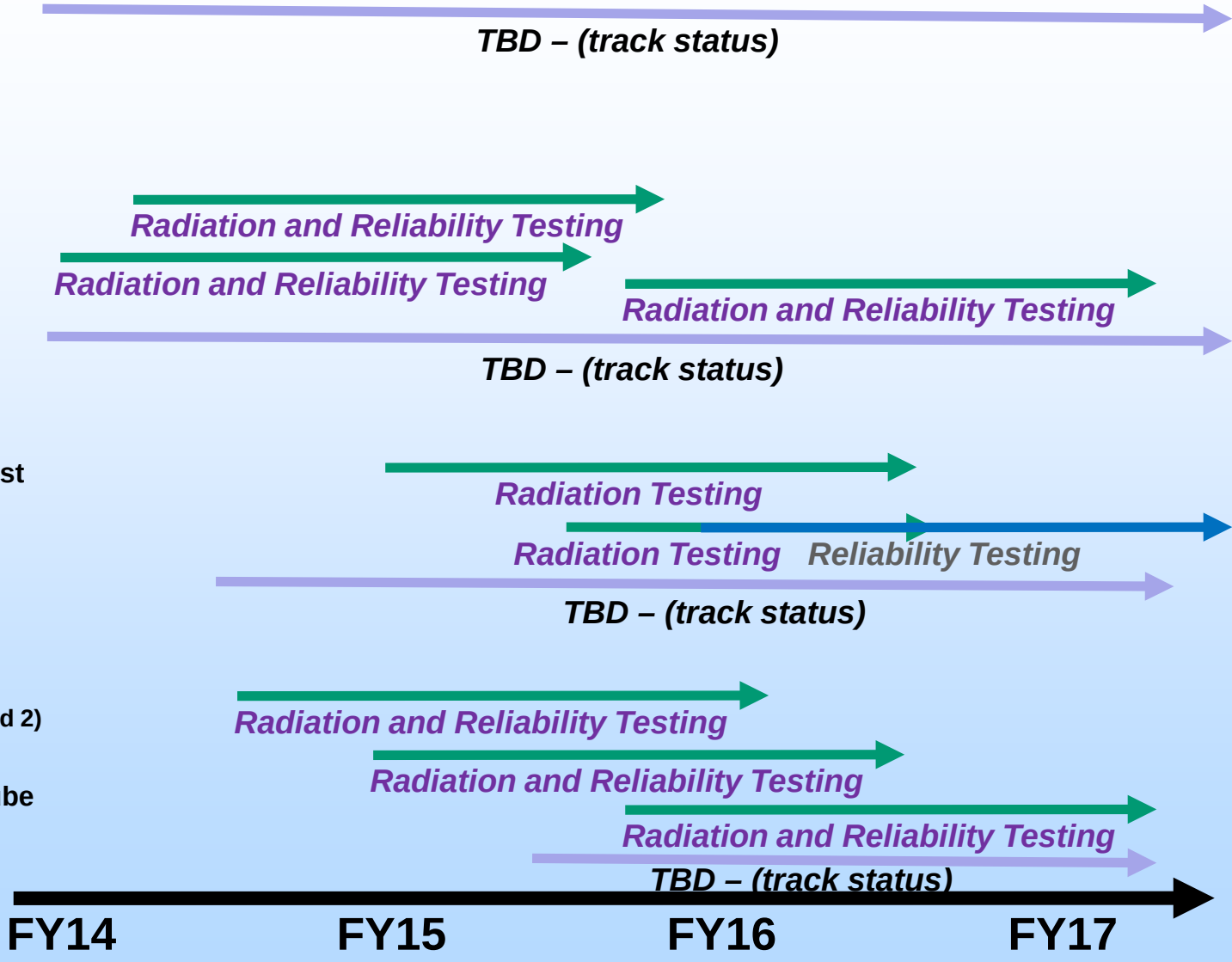
- collaborative with Navy Crane

Other
- MRAM
- FeRAM

Resistive
- CBRAM (Adesto)
- ReRAM (Panasonic)
- ReRAM (Tezzaron)
- TBD (HP Labs, others)

DDR 3/4
- Intelligent Memory (robust cell twinning)
- Micron 16nm DDR3
- TBD – other commercial

FLASH
- Samsung VNAND (gen 1 and 2)
- Micron 16nm planar
- Micron Hybrid memory Cube
- TBD - other commercial



Small Missions

EEE Parts Guidelines

- Small missions (Class D, CubeSat – 2 documents)
- System on a chip (SOC) single event effects (SEE) guideline
- Proton board level test guideline

Commodities evaluation

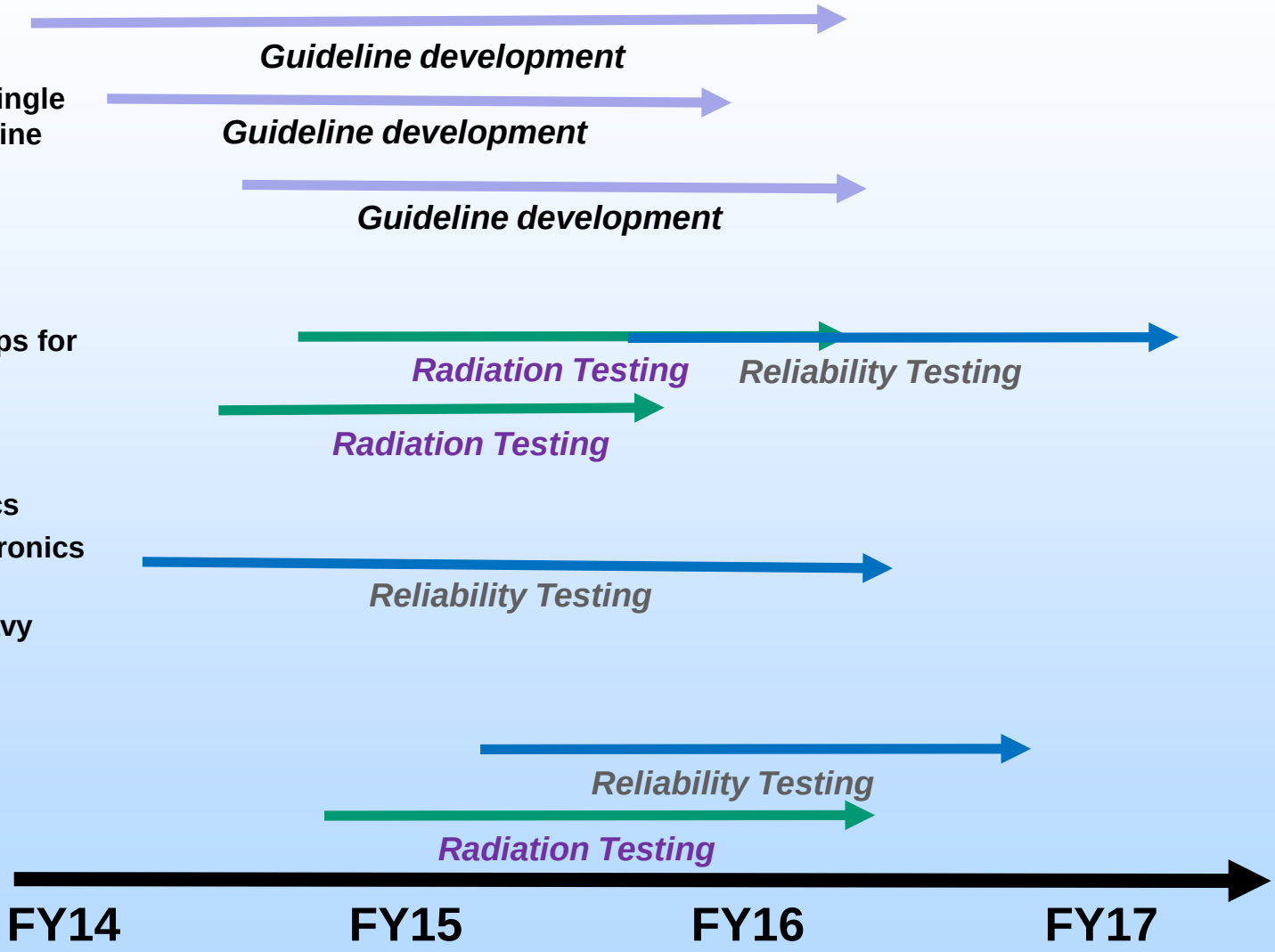
- See commodities roadmaps for processors, power
- CubeSat Star Tracker

Automotive grade electronics

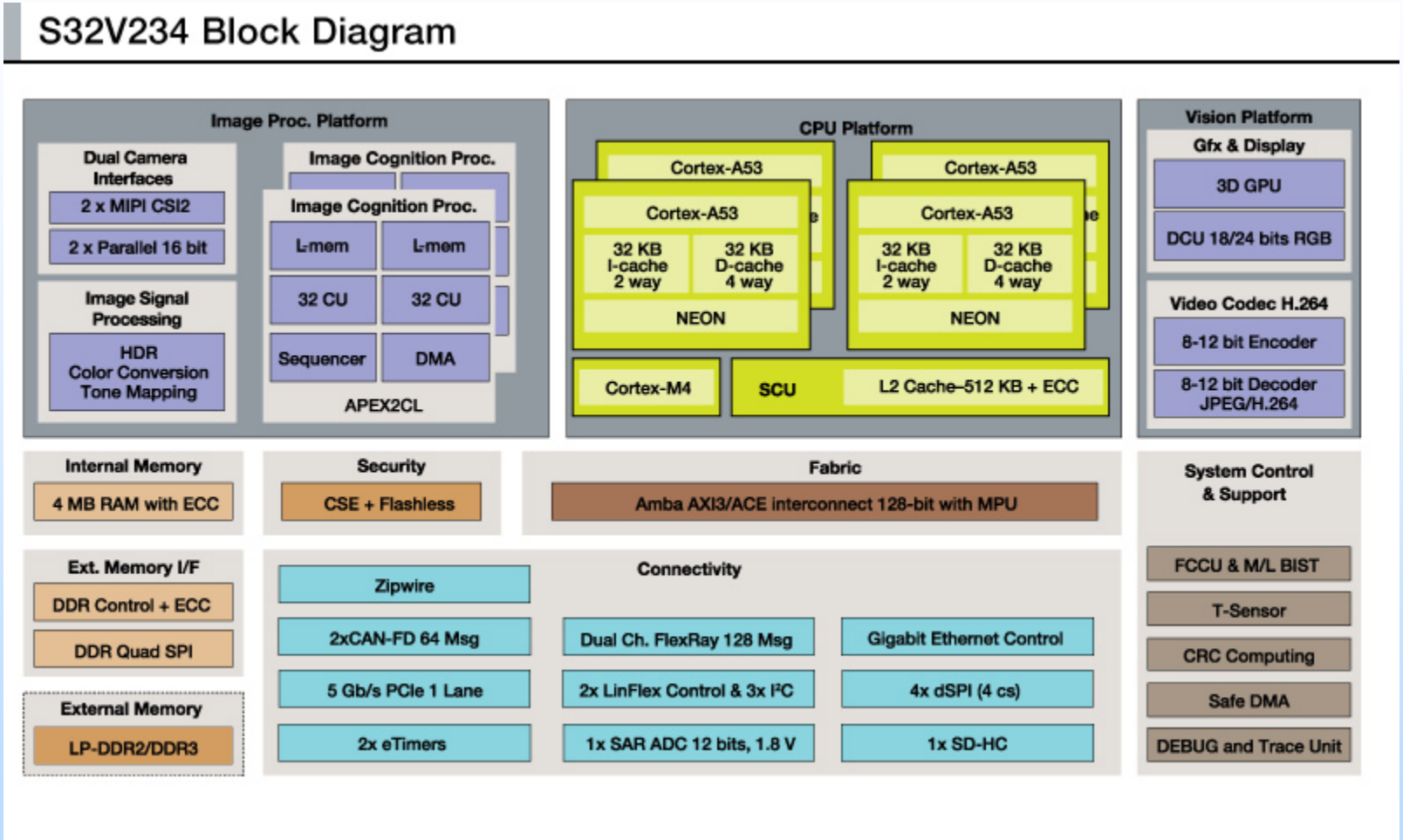
- Multiple classes of electronics (passives, actives, ICs)
- Testing by NASA and Navy Crane

Alternate test – board level

- Freescale MPC56XX
- Automotive Grade
- Both part and board level reliability testing



Automotive Processors and Systems for Self-Driving Cars?



From Freescale.com

Wide Band Gap (WBG) Technology

GaN Enhancement Mode HEMTs
- EPC Gen 2-3, 200 V - 600 V
- GaN Systems 100 V, 650 V
- Panasonic 600 V (target)
- IR/Infineon 600 V (target)

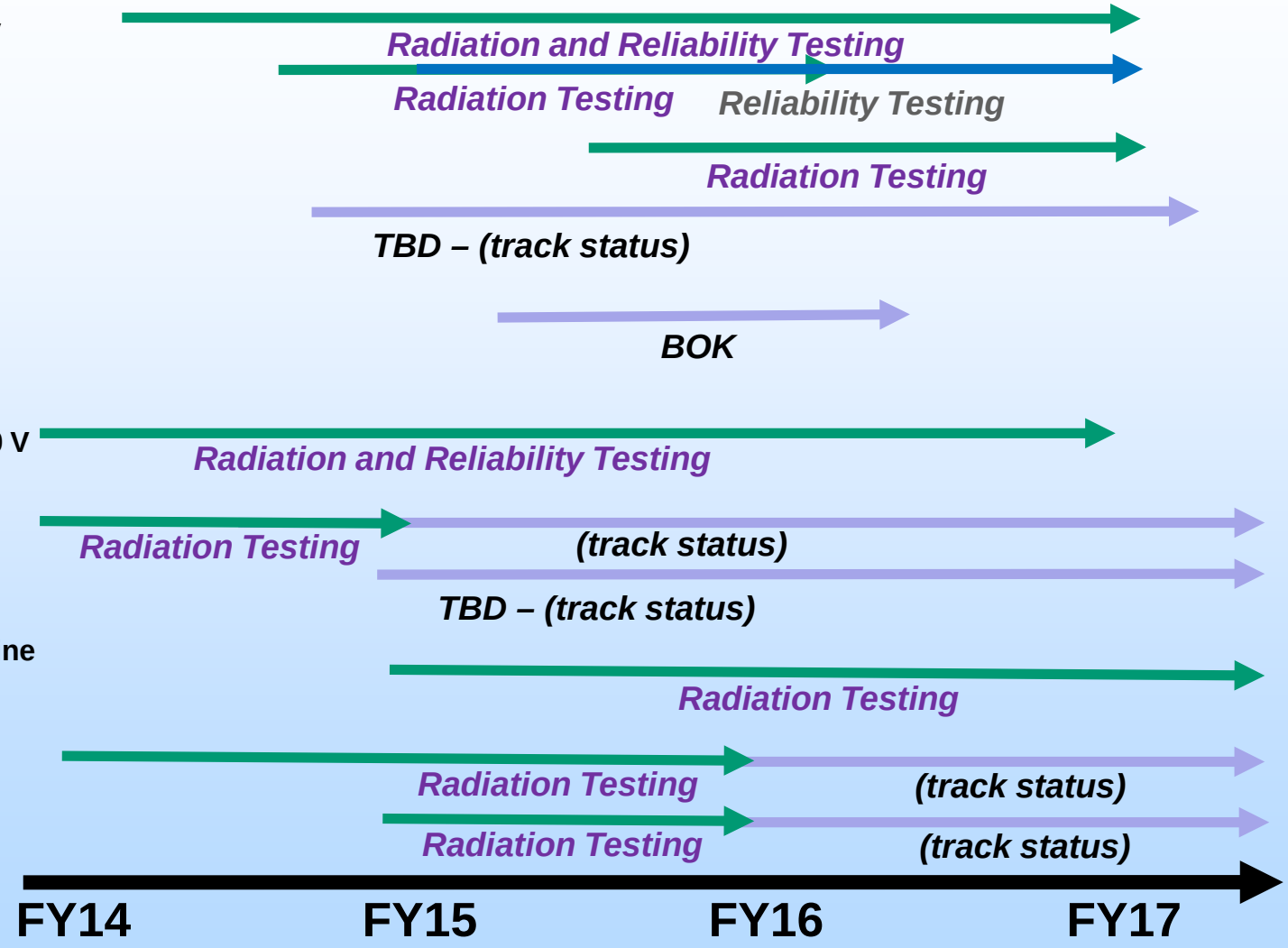
GaN Other

SiC
- Body of Knowledge (BOK) document

SiC MOSFETs
- Cree Gen 1-2 1200 V - 1700 V Gen 3- 4
- STMicro baseline SEE test
- Rohm Trench design

SiC Diodes
- Manufacturer X SEE baseline and hardening efforts

SiC ICs
- Ozark IC
- Manufacturer X



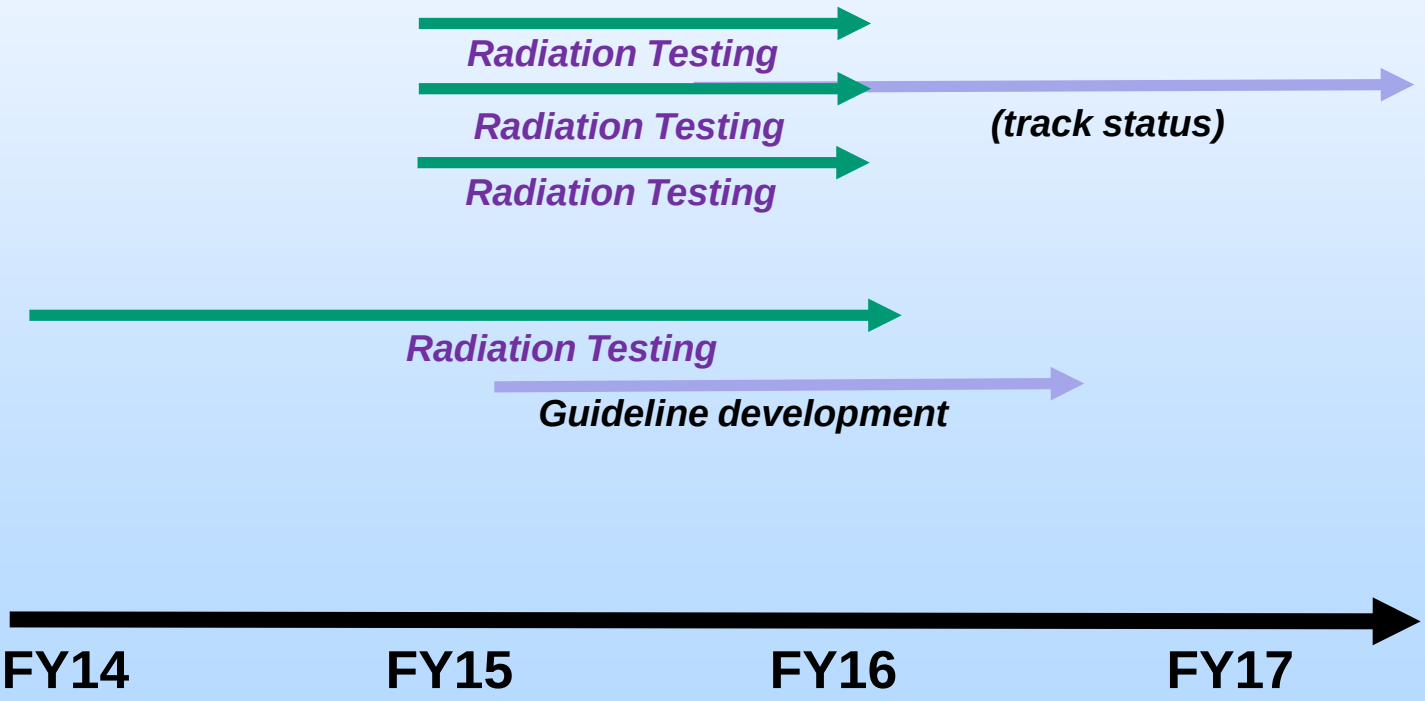
Silicon Power Devices

MOSFETs – Rad Hardened

- Microsemi i2MOS
- Infineon superjunction 100 V, 600 V (target)
- IR/Infineon R8 trench 20 V

Schottky Diodes

- Multiple vendors, reverse voltage ratings, and forward current ratings



Packaging Technologies (1 of 2)

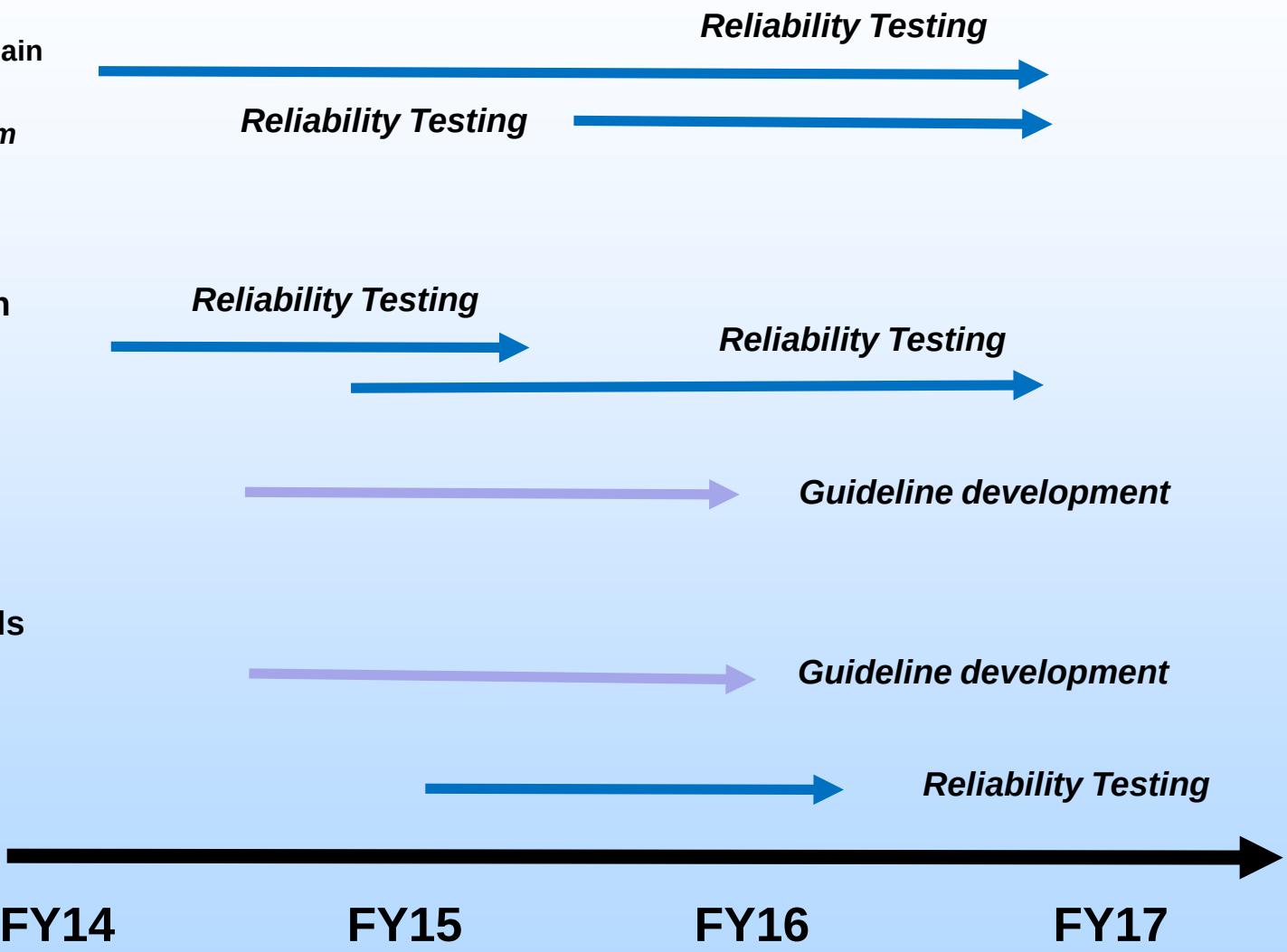
High Density, Non-hermetic Column Grid Array (CGA)
- Xilinx CN/Kyocera Daisy Chain
- Microsemi Daisy Chain
- *Materials analysis, long term stress, root cause failure*

HALT Methodology/Qualification
- HALT/HAST comparison
- Plastic BGA matrix

Area Array Column
- Selection guide

Thermal Interface Materials
- Selection guide

PBGA Thermal Cycle Evaluation



Packaging Technologies (2 of 2)

Bump Reliability
- Technology review
- Test vehicle options

Guideline research

3D Packaging Technologies
- Technology review
- Test vehicle options

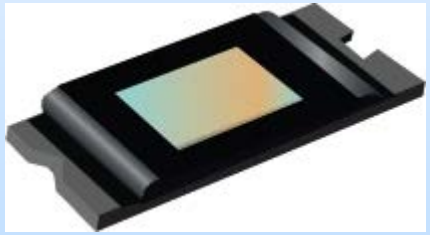
Guideline research

QFN package reliability
– Reliability/Qualification metrics

Reliability Testing

And Just When You Think Your Roadmap is Set, New Parts are Released

- **Examples**
  - **More complex processors**
    - **TI Multicore DSP+ARM KeyStone II System-on-Chip (SoC)**
  - **Integrated “instruments”**
    - **TI DLP2010NIR – near IR sensing and controller**



Courtesy, TI

A Few Other Cool Tasks…

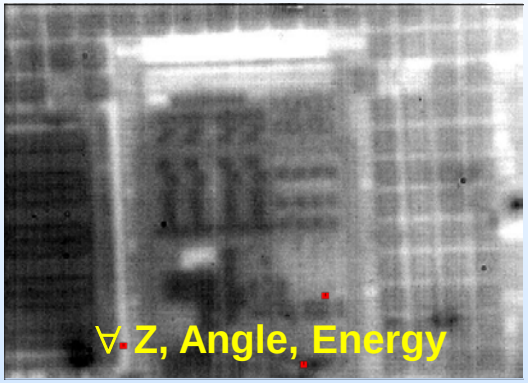
- **CubeSat mission success/failure root cause analysis**
  - **Grant to Saint Louis University**
- **Using a model-based systems engineering (MBSE) approach to radiation assurance**
  - **Grant to Vanderbilt**
  - **Co-sponsored by NASA Reliability and Maintainability Program**
  - **Uses a tool called "Goal Structured Notation"**
- **Keeping the CRÈME website alive**
  - **Support to Vanderbilt**
  - **Just standard maintenance and operation, no upgrades**
- **Proton fluence test levels**
  - **See next chart**

Relative Coverage of Proton and Heavy-Ion SEE Tests

Infrared micrograph of a portion of a 512 Mb SDRAM ~60×70 μm²

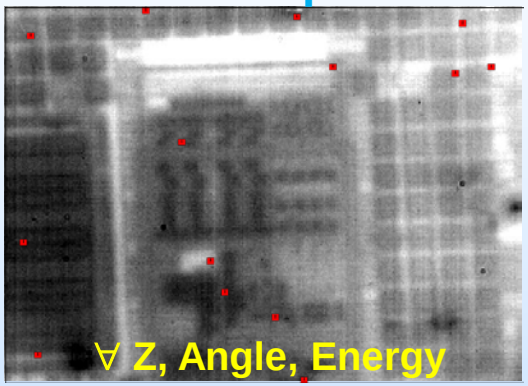
- **Shows both memory cells and control logic (10 yr. old tech.)**
- **Red spots are ion hits**

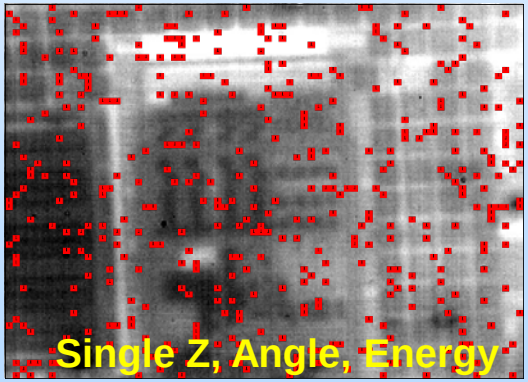
1E10 200 MeV protons/cm²



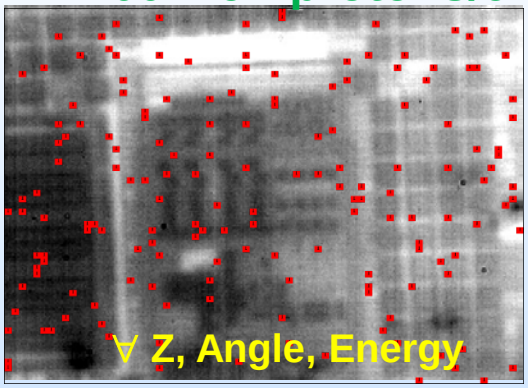
20% of areas this size get 0 hits for 10^{10} cm^{-2}

1E11 200 MeV protons/cm²





1E12 200 MeV protons/cm²



Coverage from 1E7 heavy ions/cm²

Courtesy Ray Ladbury, NASA/GSFC

Proton Therapy Site Access – Team Plan

- ✓ Contact facilities (focus on cyclotrons)
- ✓ Site visit to determine interest
  - Technical
  - Access
  - Business case
- ❑ Beta/shakeout tests at interested sites to determine usability
  - ✓ Underway
- ❑ Work logistics of access
  - ✓ Underway
- ❑ Determine guidelines for usage of these sites
  - ✓ Underway
- ❑ Recommendations for modifications and longer term access.
  - ✓ Initial planning

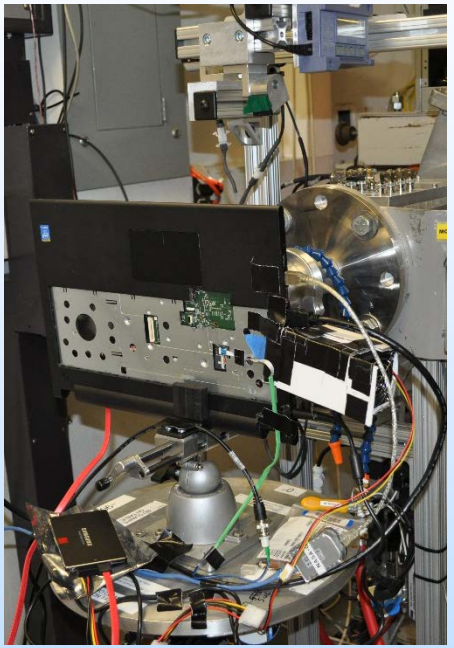
Assumption: Therapy sites will have available 300-500 hours/year each (weekends). Multiple facilities required to replace IUCF in the near term.

Proton Facility Status (200 MeV – North America)

	Facility	Location	Hourly Rate	Type	Access/ Annual Hours	Expected Avail.	Shakeout Test
Future Facilities	Northwestern Medicine Chicago Proton Center	Warrenville, IL	TBD	Cyclotron	2 hrs – weeknights 8-16 hrs Saturdays	Now	Yes
	Scripps Proton Therapy Center	La Jolla, CA	<$1000/hr	Cyclotron	Up to 500 hrs	Now	Yes
	Seattle Proton Center	Seattle, WA	TBD	Cyclotron	TBD	On hold until CY16	Yes
	Hampton University Proton Therapy Institute (HUPTI)	Hampton, VA	TBD	Cyclotron	TBD weekends (up to 30 hrs?)	CY15	Yes
	OKC ProCure Proton Therapy Center	OKC, OK	$1000 + one-time $3000 setup fee	Cyclotron	Weekdays 6 hrs + possible shared time Saturdays 5-8 hrs	On hold	Change of management – no current interest
	University of Florida Health Proton Therapy Institute (UFHPTI)	Jacksonville, FL	TBD	Cyclotron	Weekend days (possibly shared with quality assurance)	CY16	Spring CY16
	Provision Center for Proton Therapy	Knoxville, TN	TBD	Cyclotron	TBD	Unknown	Unknown
	Dallas Proton Treatment Center	Dallas, TX	TBD	Cyclotron	TBD	On "pause"	TBD
	University of Maryland Proton Treatment Center	Baltimore, MD	TBD	Cyclotron	500	CY16	Spring CY16?
Existing Facilities	Tri-University Meson Facility (TRIUMF)	Vancouver, CAN	$750	Cyclotron	4x/year	Yes	Oct-Nov 2015
	Slater Proton Treatment and Research Center at Loma Linda University Medical Center (LLUMC)	Loma Linda, CA	$1,000	Synchrotron	~1000	Yes	N/A
	Mass General Francis H. Burr Proton Therapy (MGH)	Boston, MA	$650	Cyclotron	~800 hours 12hr weekend days, 3 of 4 weekends – 6 month+ lead time	Yes	Dec 2015
	NASA Space Radiation Lab (NSRL)	Brookhaven, NY	$4,700	Synchrotron	~1000 hours	Yes	N/A
	Indiana University Cyclotron Facility	Bloomington, IN	$820	Cyclotron	2000 hours	No	N/A

INTEL 14nm Processors

- **Two generations now available:**
  - **5th (laptop focused with LOW power)**
  - **6th (high performing)**
- **Initial proton and heavy ion tests performed on 5th generation**
  - **SEUs as expected on commercial devices**
  - **Anomaly observed during heavy ion tests**
    - **1 sample, 45 deg incident angle, <10 linear energy transfer (LET)**
    - **Device crashed and failed to come back to life after power removal, change of disk drive, power source, etc…**
    - **"Annealed" (i.e., working) upon equipment being shipped back to home site**
    - **Verified by a second group (saw similar response)**
- **More testing planned on both generations**



Testing laptop with heavy ions, Ken LaBel

Summary and Comments

- **NEPP Roadmaps are constantly evolving as technology and products become available.**
  - **Like all technology roadmaps, NEPP's is limited to funding and resource availability.**
  - **Not shown are TBD passives and connector roadmaps under development.**
  - **Partnering is the key:**
    - **Government,**
    - **Industry, and,**
    - **University.**
- **We look forward to further opportunities to partner.**

https://nepp.nasa.gov