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

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Open Access
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

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>ADC</td>
<td>analog-to-digital converter</td>
</tr>
<tr>
<td>AES</td>
<td>Advanced Encryption Standard</td>
</tr>
<tr>
<td>AF SMC</td>
<td>Air Force Space &amp; Missile Systems Center</td>
</tr>
<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
</tr>
<tr>
<td>AMOLED</td>
<td>Active Matrix Organic Light Emitting Diode</td>
</tr>
<tr>
<td>AMS</td>
<td>Agile Mixed Signal</td>
</tr>
<tr>
<td>ARM</td>
<td>ARM Holdings Public Limited Company</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network</td>
</tr>
<tr>
<td>CAN-FD</td>
<td>Controller Area Network Flexible Data-Rate</td>
</tr>
<tr>
<td>CBRAM</td>
<td>Conductive Bridging Random Access Memory</td>
</tr>
<tr>
<td>CCI</td>
<td>Correct Coding Initiative</td>
</tr>
<tr>
<td>CGA</td>
<td>Column Grid Array</td>
</tr>
<tr>
<td>CIGS</td>
<td>Copper Indium Gallium Selenide</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary Metal Oxide Semiconductor</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>CPU</td>
<td>Computer Processing Unit</td>
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<tr>
<td>CRC</td>
<td>Cyclic Redundancy Check</td>
</tr>
<tr>
<td>CREME</td>
<td>Cosmic Ray Effects on Micro-Electronics</td>
</tr>
<tr>
<td>CSE</td>
<td>Computer Science and Engineering</td>
</tr>
<tr>
<td>Cu</td>
<td>Cu alloy</td>
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<tr>
<td>D-Cache</td>
<td>Data Cache</td>
</tr>
<tr>
<td>DCU</td>
<td>Display Controller Unit</td>
</tr>
<tr>
<td>DDR</td>
<td>Double Data Rate</td>
</tr>
<tr>
<td>DDR2</td>
<td>Double Data Rate Two</td>
</tr>
<tr>
<td>DDR3</td>
<td>Double Data Rate Three</td>
</tr>
<tr>
<td>DDR4</td>
<td>Double Data Rate Four</td>
</tr>
<tr>
<td>DMA</td>
<td>Direct Memory Access</td>
</tr>
<tr>
<td>DNA</td>
<td>Deoxyribonucleic Acid</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>DRAM</td>
<td>Dynamic Random Access Memory</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital Signal Processing</td>
</tr>
<tr>
<td>dsSPI</td>
<td>Dynamic Signal Processing Instrument</td>
</tr>
<tr>
<td>DTRA</td>
<td>Defense Threat Reduction Agency</td>
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<tr>
<td>Dual Ch</td>
<td>Dual Channel</td>
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<tr>
<td>ECC</td>
<td>Error-Correcting Code</td>
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<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
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<tr>
<td>EMAC</td>
<td>Equipment Monitor And Control</td>
</tr>
<tr>
<td>EPC</td>
<td>Efficient Power Conversion</td>
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<tr>
<td>ESL</td>
<td>Electronic System Level</td>
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<tr>
<td>eTimers</td>
<td>Event Timers</td>
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<tr>
<td>FCCU</td>
<td>Fluidized Catalytic Cracking Unit</td>
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<tr>
<td>FeRAM</td>
<td>Ferroelectric RAM</td>
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<tr>
<td>FinFET</td>
<td>Fin Field Effect Transistor (the conducting channel is wrapped by a thin silicon &quot;fin&quot;)</td>
</tr>
<tr>
<td>FlexRay</td>
<td>FlexRay communications bus</td>
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<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
</tr>
<tr>
<td>FY</td>
<td>Fiscal Year</td>
</tr>
<tr>
<td>GaN</td>
<td>Gallium Nitride</td>
</tr>
<tr>
<td>Gb/s</td>
<td>gigabyte per second</td>
</tr>
<tr>
<td>Gen</td>
<td>Generation</td>
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<tr>
<td>GIC</td>
<td>Global Industry Classification</td>
</tr>
<tr>
<td>GPU</td>
<td>Graphics Processing Unit</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>HALT</td>
<td>Highly Accelerated Life Test</td>
</tr>
<tr>
<td>HAST</td>
<td>Highly Accelerated Stress Testing</td>
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<tr>
<td>HDIO</td>
<td>High Density Digital Input/Output</td>
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<tr>
<td>HDR</td>
<td>High-Dynamic-Range</td>
</tr>
<tr>
<td>HEMTs</td>
<td>High-electron-mobility transistors</td>
</tr>
<tr>
<td>HP Labs</td>
<td>Hewlett-Packard Laboratories</td>
</tr>
<tr>
<td>HPIO</td>
<td>High Performance Input/Output</td>
</tr>
<tr>
<td>HUPTI</td>
<td>Hampton University Proton Therapy Institute</td>
</tr>
<tr>
<td>HW</td>
<td>Hardware</td>
</tr>
<tr>
<td>I2C</td>
<td>Inter-Integrated Circuit</td>
</tr>
<tr>
<td>IBM</td>
<td>International Business Machines</td>
</tr>
<tr>
<td>IBM/GF</td>
<td>International Business Machines/GlobalFoundaries</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>I-Cache</td>
<td>Instruction Cache</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IP</td>
<td>Intellectual Property</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>IR/Infineon</td>
<td>International Rectifier/Infineon Technologies</td>
</tr>
<tr>
<td>IUCF</td>
<td>Indiana University Cyclotron Facility</td>
</tr>
<tr>
<td>JPEG</td>
<td>Joint Photographic Experts Group</td>
</tr>
<tr>
<td>KB</td>
<td>Kilobyte</td>
</tr>
<tr>
<td>L2 Cache</td>
<td>independent caches organized as a hierarchy (L1, L2, etc.)</td>
</tr>
<tr>
<td>LCoS</td>
<td>Liquid-Crystal-on-Silicon</td>
</tr>
<tr>
<td>LET</td>
<td>linear energy transfer</td>
</tr>
<tr>
<td>LinFlex</td>
<td>Local Interconnect Network Flexible</td>
</tr>
<tr>
<td>LLUMC</td>
<td>Slater Proton Treatment and Research Center at Loma Linda University Medical Center</td>
</tr>
<tr>
<td>L-mem</td>
<td>Long-Memory</td>
</tr>
<tr>
<td>LP</td>
<td>Low Power</td>
</tr>
<tr>
<td>ML BIST</td>
<td>Memory/Logic Built-In Self-Test</td>
</tr>
<tr>
<td>MBSE</td>
<td>Model-Based Systems Engineering</td>
</tr>
<tr>
<td>MENS</td>
<td>Micro Electrical-Mechanical System</td>
</tr>
<tr>
<td>MGH</td>
<td>Mass General Francis H. Burr Proton Therapy</td>
</tr>
<tr>
<td>MIP</td>
<td>Mobile Industry Processor Interface</td>
</tr>
<tr>
<td>MOSFETS</td>
<td>Metal Oxide Semiconductor Field Effect Transistors</td>
</tr>
<tr>
<td>MPSoc</td>
<td>Multi-Processor System on a Chip</td>
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<tr>
<td>MRAM</td>
<td>Magnetoresistive Random Access Memory</td>
</tr>
<tr>
<td>Msg</td>
<td>Message</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NAVY Crane</td>
<td>Naval Surface Warfare Center, Crane, Indiana</td>
</tr>
<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
</tr>
<tr>
<td>NGSP</td>
<td>Next Generation Space Processor</td>
</tr>
<tr>
<td>NOR</td>
<td>Not OR logic gate</td>
</tr>
<tr>
<td>NSRL</td>
<td>NASA Space Radiation Lab</td>
</tr>
<tr>
<td>Occam</td>
<td>Open Conditional Content Access Management</td>
</tr>
<tr>
<td>OKC</td>
<td>Oklahoma City</td>
</tr>
<tr>
<td>OLED</td>
<td>Organic Light Emitting Diode</td>
</tr>
<tr>
<td>PBGA</td>
<td>Plastic Ball Grid Array</td>
</tr>
<tr>
<td>PCIe</td>
<td>Peripheral Component Interconnect Express</td>
</tr>
<tr>
<td>PCIe Gen2</td>
<td>Peripheral Component Interconnect Express Generation 2</td>
</tr>
<tr>
<td>PCIe Gen4</td>
<td>Peripheral Component Interconnect Express Generation 4</td>
</tr>
<tr>
<td>PS-GT</td>
<td>Global Regulation on Pedestrian Safety</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>ReRAM</td>
<td>Resistive Random Access Memory</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>RGB</td>
<td>Red, Green, and Blue</td>
</tr>
<tr>
<td>RH</td>
<td>RAD-Hard</td>
</tr>
<tr>
<td>SAR</td>
<td>Successive-Approximation-Register</td>
</tr>
<tr>
<td>SATA</td>
<td>Serial Advanced Technology Attachment</td>
</tr>
<tr>
<td>SCU</td>
<td>Secondary Control Unit</td>
</tr>
<tr>
<td>SD/eMMC</td>
<td>Secure Digital embedded MultiMediaCard</td>
</tr>
<tr>
<td>SD-HC</td>
<td>Secure Digital High Capacity</td>
</tr>
<tr>
<td>SDRAM</td>
<td>Synchronous Dynamic Random Access Memory</td>
</tr>
<tr>
<td>SEE</td>
<td>Single Event Effect</td>
</tr>
<tr>
<td>SERDES</td>
<td>Serializer/Deserializer</td>
</tr>
<tr>
<td>SiC</td>
<td>Silicon Carbide</td>
</tr>
<tr>
<td>SMRU</td>
<td>System Memory Management Unit</td>
</tr>
<tr>
<td>SOC</td>
<td>System on a chip</td>
</tr>
<tr>
<td>SPI</td>
<td>Serial Peripheral Interface</td>
</tr>
<tr>
<td>SPU</td>
<td>Synergistic Processor Unit</td>
</tr>
<tr>
<td>TCM</td>
<td>Tightly Coupled Memory</td>
</tr>
<tr>
<td>TI</td>
<td>Texas Instruments</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>T-Sensor</td>
<td>Temperature-Sensor</td>
</tr>
<tr>
<td>TSMC</td>
<td>Taiwan Semiconductor Manufacturing Company</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver/Transmitter</td>
</tr>
<tr>
<td>UFHPTI</td>
<td>University of Florida Health Proton Therapy Institute</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>VNAND</td>
<td>Vertical NAND</td>
</tr>
<tr>
<td>WBG</td>
<td>Wide Band Gap</td>
</tr>
<tr>
<td>WDT</td>
<td>Watchdog Timer</td>
</tr>
</tbody>
</table>

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 (e.g., 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 for Emerging Technologies 2015

http://www.gartner.com/newsroom/id/3114217
# NEPP and Gartner Electronics Hype Cycle 2013

**Benefit**
- Transformational
  - LCoS
  - Magnetometer
  - Network on Chip
- High
  - CIGS Thin-Film Solar Cells
  - CMOS RF Power Amplifier
  - ESL Design Tools and Methodologies
  - HW Reconfigurable Devices
  - IC Subsystem Reuse
  - Multicore Programming
  - Nanomaterial Supercapacitors
  - Post-193 nm Lithography
  - Printed Semiconductors
  - Reusable Analog IP
  - Silicon Anode Batteries
- Moderate
  - Resistance Phase-Change Memory
  - Through Silicon Vias
  - AMOLED
  - Electronic Paper
  - Lithium Ion Phosphate Batteries
  - MEMS Gyroscopes
  - Metamaterial Antennas
  - Wireless Power
- Low
  - DDR4 DRAM

**Years to adopt:**
- less than 2 years
  - Silicon Photonics
  - Software-Defined Radio for Mobile Devices
- 2 to 5 years
  - Memristor Memory
  - Nanotube Electronics
  - 3D Photovoltaic Devices
  - 450 nm Wafers
  - Biochips
  - GaN ICs
  - Micro Fuel Cells
  - Spin Transfer Torque Magnetic Random-Access Memory
  - System on a Package
  - FPGA in SOC
  - Instruction Set Virtualization
  - MEMS Displays
  - Occam Process
  - OLED Lighting
  - Photonic Crystal Displays
  - Quantum Dot Displays
  - Silicon Thin-Film Solar Cells
- 5 to 10 years
  - DNA Logic
  - Molecular Transistors
  - Organic/Polymer Solar Cells
  - Quantum Computing
  - Resistance Polymer Memory
  - Terahertz Waves
  - Holographic Storage for Consumer Electronics
- more than 10 years
  - Cognitive Radio

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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)

Radiation Testing
Reliability Testing
Radiation and Reliability Testing
Package Reliability Testing

FY14 FY15 FY16 FY17
TBD – (track status)
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

RH Processor
- BAE Systems RAD5510/5545
- Replacement for RAD750

Intel Processors (w/Navy Crane)
- 14nm FinFET commercial (5th and 6th generation)
- 5th generation is 1st high-performance sans heatsink (lower power for performance)

Freescale P5020/5040
- Commercial 45nm network processor
- Preparation for RH processor

TBD – (track status)

FY14 FY15 FY16 FY17

Radiation Testing
Reliability Testing
Radiation Testing
Reliability Testing
Radiation Testing

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

FY14 FY15 FY16 FY17

TBD – (others)
Radiation Testing (limited)
Reliability Testing
Radiation Testing
Reliability Testing
Radiation 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
- 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

FY14 FY15 FY16 FY17

TBD – (track status)

BOK

Radiation and Reliability Testing

Radiation Testing

Reliability Testing

Radiation Testing

Radiation Testing

Radiation Testing

Radiation Testing

Radiation Testing

Radiation Testing

Manufacturers' targets and hardening efforts.
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

Radiation Testing (track status)
Radiation Testing
Radiation Testing

Guideline development

FY14 FY15 FY16 FY17

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

Reliability Testing

Guideline development

FY14 FY15 FY16 FY17

Bump Reliability
- Technology review
- Test vehicle options

3D Packaging Technologies
- Technology review
- Test vehicle options

QFN package reliability
- Reliability/Qualification metrics

Guideline research
Guideline research
Reliability Testing

FY14 FY15 FY16 FY17

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 1E11 200 MeV protons/cm² 1E12 200 MeV protons/cm²


20% of areas this size get 0 hits for 10¹⁰ cm⁻²

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)

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

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

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