The NASA Electronic Parts and Packaging (NEPP) Program: Overview and Update FY15 and Beyond

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Deliverable to NASA Electronic Parts and Packaging (NEPP) Program to be published on nepp.nasa.gov originally presented by Kenneth LaBel and Michael Sampson at the Space Parts Working Group (SPWG) 2015, Torrance, CA, April 28-29, 2015.
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEC</td>
<td>Automotive Electronics Council</td>
</tr>
<tr>
<td>Aero</td>
<td>Aerospace</td>
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<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
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<tr>
<td>BME</td>
<td>Base Metal Electrode</td>
</tr>
<tr>
<td>CA</td>
<td>Construction Analysis</td>
</tr>
<tr>
<td>CBRAM</td>
<td>Conductive Bridging Random Access Memory</td>
</tr>
<tr>
<td>CDH</td>
<td>Cadence Health, Central DuPage Hospital Proton Facility</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>CSAM</td>
<td>Confocal Scanning Acoustic Microscopy</td>
</tr>
<tr>
<td>DWV</td>
<td>Dielectric Withstanding Voltage</td>
</tr>
<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
</tr>
<tr>
<td>FeRAM</td>
<td>Ferroelectric RAM</td>
</tr>
<tr>
<td>FOD</td>
<td>Foreign Object Debris</td>
</tr>
<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>GSFC</td>
<td>Goddard Space Flight Center</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>HUPTI</td>
<td>Hampton University Proton Therapy Institute</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>IUCF</td>
<td>Indiana University Cyclotron Facility</td>
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<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratories</td>
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>LLUMC</td>
<td>James M. Slater Proton Treatment and Research Center at Loma Linda University Medical Center</td>
</tr>
<tr>
<td>MGH</td>
<td>Massachusetts General Hospital</td>
</tr>
<tr>
<td>MIL</td>
<td>Military</td>
</tr>
<tr>
<td>MLCC</td>
<td>Multi-Layer Ceramic Capacitor</td>
</tr>
<tr>
<td>MOSFETS</td>
<td>Metal Oxide Semiconductor Field Effect Transistors</td>
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<tr>
<td>MRAM</td>
<td>Magnetoresistive Random Access Memory</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>
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<tr>
<td>NEPAG</td>
<td>NASA Electronic Parts Assurance Group</td>
</tr>
<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
</tr>
<tr>
<td>NSRL</td>
<td>NASA Space Radiation Laboratory</td>
</tr>
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<td>POC</td>
<td>Point of Contact</td>
</tr>
<tr>
<td>ProCure</td>
<td>ProCure Center, Warrenville, Illinois</td>
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<tr>
<td>RERAM</td>
<td>Resistive Random Access Memory</td>
</tr>
<tr>
<td>SEE</td>
<td>Single Event Effect</td>
</tr>
<tr>
<td>SiC</td>
<td>Silicon Carbide</td>
</tr>
<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
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<tr>
<td>SOC</td>
<td>Systems on a Chip</td>
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<tr>
<td>TI</td>
<td>Texas Instruments</td>
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<td>TRIUMF</td>
<td>Tri-University Meson Facility</td>
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<tr>
<td>UCD</td>
<td>University of California at Davis (UCD) Crocker Nuclear Lab (CNL)</td>
</tr>
<tr>
<td>VNAND</td>
<td>Vertical NAND</td>
</tr>
</tbody>
</table>
INTRODUCTION TO NEPP
Taking a Step Back…
A Simple View of NEPP’s Perspective

**NEPP Efforts Relate to Assurance of EEE Parts** –
It’s not just the technology, but how to view the need for safe insertion into space programs.
A View of NASA Electrical, Electronic, and Electromechanical (EEE) Parts Needs – *Diversity*!

- **Commercial Crew**
  - Focus on fail-safe architecture/electronics

- **Manned Mars**
  - Focus on reliability and radiation tolerance
  - Overlap areas are critical assurance infrastructure
    (NASA Electronic Parts Assurance Group - NEPAG)

- **Small Missions**
  - Focus on cost-consciousness and low power electronics

Without forgetting traditional LEO and Deep-Space Robotic needs

*LEO=Low Earth Orbit*
*NEPAG=NASA Electronic Parts Assurance Group*
NEPP Overview (1)

**NEPP provides the Agency infrastructure for assurance of EEE parts for space usage**

**Qualification guidance**
To flight projects on how to qualify

**Technology Evaluation**
Determine new technology applicability and qualification guidance

**Standards**
Ensures NASA needs are represented

**Test/Qualification Methods**
Evaluate improved or more cost-effective concepts

**Manufacturer Qualification**
Support of audits and review of qualification plans/data

**Risk Analysis**
For all grades of EEE parts (commercial, automotive, military/aerospace, …)

**Information Sharing**
Lessons learned, working groups, website, weekly telecons

**Subject Matter Experts (SMEs)** for NASA programs, other agencies, industry

**NEPP and its subset (NEPAG) are the Agency’s points of contact (POCs) for assurance and radiation tolerance of EEE parts and their packages.**

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As opposed to a traditional breakdown of parts, packaging, or radiation, **NEPP tasks can be categorized into these five areas**.

**NEPP Top-Level Task Areas**

- **Automotive/Commercial Electronics**
- **Complex Devices (Commercial/Mil-Aero)**
- **Assurance**
- **Power Devices (Commercial/Mil-Aero)**
- **NEPAG**
NEPP TECHNOLOGY ROADMAP
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: Commercial off the shelf (COTS) to high reliability aerospace.

• Partnering arrangements with other organizations preferred.

• In general, we avoid:
  – Laboratory technologies, e.g., < Technology Readiness Level (TRL) 3,
  – Limited application devices with certain exceptions (critical application or NASA center specialization).
Technology Investigation Roadmap

Discussion

• Technology assurance efforts through NEPAG 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 communications (serializer-deserializer (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.

• Note 2: “Reliability testing” may include product and/or package testing.

• Note 3: Roadmap updates based on early results.
Field Programmable Gate Arrays (FPGAs)

Trusted FPGA
- DoD Development

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

Microsemi
- RTG4 (65nm RH)

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

FY14 FY15 FY16 FY17

TBD – (track status)

Radiation Testing
Reliability Testing
Radiation and Reliability Testing
Package Reliability Testing

FY=Fiscal Year

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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 Broadwell Processors
- 14nm FinFET commercial
- 1st high-performance sans heatsink

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

TBD – (track status)

<table>
<thead>
<tr>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Radiation Testing
Reliability Testing

Note: Future considerations include automotive “self-driving” processor options.

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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 (limited)

TI=Texas Instruments

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Commercial Memory Technology

Other
- MRAM
- FeRAM

Resistive
- CBRAM (Adesto)
- ReRAM (Panasonic)
- ReRAM (Tezzeron)
- 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 hypercube
- TBD - other commercial

TBD – (track status)

FY14 FY15 FY16 FY17

MRAM= Magnetoresistive Random Access Memory
FeRAM= Ferroelectric RAM
CBRAM= Conductive Bridging Random Access Memory
ReRAM= Resistive Random Access Memory
HP Labs= Hewlett-Packard Laboratories
VNAND= Vertical NAND

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Small Missions

EEE Parts Guidelines
- Small missions (Class D, CubeSat – 2 documents)
- System on a chip (SOC single event effects (SEE) 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

Guideline development
FY14  FY15  FY16  FY17

Radiation Testing  Reliability Testing

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# NEPP Evaluation Automotive Grade Parts – Current Status

**Parts were purchased through distributors as Automotive Electronics Council (AEC) Q-”XXX” Automotive Grade**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Test</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ceramic Capacitors</strong></td>
<td>Construction Analysis</td>
<td>Complete</td>
<td>• At their own discretion a manufacturer supplied devices made with “flexible termination”</td>
</tr>
<tr>
<td>3 Different Mfrs</td>
<td>Initial Parametric Measurements</td>
<td>Complete</td>
<td>• No Failures</td>
</tr>
</tbody>
</table>
| Base Metal Electrode (BME), 0805, 0.47uF, 50V | Life Test (2x Vrated, 125°C)     | > 6000 Hrs Complete (Progressing to 10k hours) | • 1 lot exhibits 5 life test failures (120pc) up to 6000 hrs  
  • 2 failures at 3100 hrs; 3 failures at 4700 hrs  
  • 2 lots exhibit no life test failures up to ~5500 hrs |
| **Integrated Circuits** | Construction Analysis             | In Process                      | • FOD on Terminals “As-Received” (Linear IC)                            |
| 2 Different Mfrs        | Initial Parametric Measurements   | In Process                      | • Tg measurements complete                                             |
| 1 digital IC (Diff Bus Driver); 1 linear IC (Comparator) | Burn-In & Life Test              | Begin 04/15                     | • CSAM complete for digital IC                                          |
|                         |                                   |                                 | • CA to be performed at end of test                                    |
Observations from NEPP Automotive Grade EEE Parts Evaluation

MLCC Life Test Failure
Catastrophic Short Circuit

FOD on IC Terminations “As-Received”

EEE=Electrical, Electronic, and Electromechanical
MLCC=Multi-Layer Ceramic Capacitor
FOD=Foreign Object Debris
IC=Integrated Circuit

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Wide Band Gap (WBG) Technology

GaN Class V development
- Microsemi with EPC

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)

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

SiC Diodes
- Manufacturer X SEE baseline and hardening efforts

SiC ICs
- Ozark IC
- Manufacturer X

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GaN=Gallium Nitride
HEMTs=High-electron-mobility transistors
SiC=Silicon Carbide
MOSFETS=Metal Oxide Semiconductor Field Effect Transistors
ICs=Integrated Circuits
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)

FY14  FY15  FY16  FY17
Charts Under Development

- Power conversion (hybrid/monolithic/CubeSat)
- Passives
- Connectors
- Packaging
ALL ABOUT PROTONS
Indiana University Cyclotron Facility (IUCF) Closure

- IUCF has been the most used higher energy proton test facility for most of the U.S. space industry (electronics).
  
  - It is primarily a medical facility that NASA and others have supported to develop a parallel capability for proton testing of electronics.
    
    - ~2000+ hours of use per year for electronics testing
    

- High energy Proton Test (>200 MeV) is Critical to Space Community.

- Possible options:
  
  - Use of Tri-University Meson Facility (TRIUMF) – Vancouver, Canada
    
    - Challenges with “border crossing”, limited “cycles” of availability
    
    - **UPDATE: TRIUMF is working w US State Dept for easier access and HW transfer**
  
  - Massachusetts General Hospital (MGH) Francis H. Burr Proton Therapy Center (additional access limited beyond current beam amounts),
  
  - University of California at Davis (UCD) Crocker Nuclear Lab (CNL)
    
    - Lower prime energy (63 MeV) does not meet all test requirements,

  - Lawrence Berkeley National Laboratories (LBNL) – (50 MeV) has similar technical challenges as CNL,

  - Loma Linda University Medical Center (LLUMC) and NASA Space Radiation Laboratory (NSRL) – have pulsed beam and some technical limits, and,

  - Multiple other proton medical therapy centers
    
    - See: [http://proton-therapy.org](http://proton-therapy.org) for example listing.

- Ad hoc team formed to investigate options.
Team Members
(min. 1 site visit)

• NASA
  – Ken LaBel, Chuck Foster (consultant)

• The Aerospace Corporation
  – Tom Turflinger, Andy Kostic, Rich Haas, Jeff George

• Integrity Applications Incorporated (IAI)
  – Brian Wie

• Vanderbilt University
  – Robert Reed

• Boeing
  – Jerry Wert, Sudhakar Shetty

• BAE Systems
  – Reed Lawrence, John Davis

• Jet Propulsion Laboratory
  – Steve Guertin
Ad Hoc “Team” Plan – Proton Therapy Sites

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

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

Note: Special Session with facilities planned at Single Event Effects (SEE) Symposium – May 18-21 2015 in La Jolla, CA

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Challenges Identified with Using Proton Therapy Facilities

• Technical
  – Beam structure and delivery are mostly different than we are used to. *This is the largest technical concern.*
  – Beam intensity control: translation between SEE test parameters and tumor delivery.
  – Remote-controlled movement of test article mounting stage may not exist at all sites – time hindrance.
  – Dosimetry at target site needs evaluation.
  – Beam stops required (therapy “stops” beam in patient).
  – Radiation dosage limits may impact some higher fluence tests.

• Logistics
  – Access
  – Scheduling
  – Cost

*Shakeout testing at Cadence Proton Center, Warrenville, IL*
## Proton Facility Status

<table>
<thead>
<tr>
<th>Facility</th>
<th>Location</th>
<th>Visit</th>
<th>Beam Attributes*</th>
<th>User friendly**</th>
<th>Hourly Rate</th>
<th>Invest. required</th>
<th>Annual Hours</th>
<th>Current Avail.</th>
<th>Short term Avail.</th>
<th>Long term Avail.</th>
<th>Beta Test</th>
</tr>
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<tbody>
<tr>
<td><strong>Future Facilities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadence Health (CDH) Proton Facility - ProCure</td>
<td>Warrenville, IL</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Mar 7</td>
</tr>
<tr>
<td>Hampton University Proton Therapy Institute (HUPTI)</td>
<td>Hampton, VA</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>350</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>TBD</td>
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<tr>
<td>Provision Center for Proton Therapy</td>
<td>Knoxville, TN</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>No</td>
<td>Maybe</td>
<td>TBD</td>
</tr>
<tr>
<td>Seattle Cancer Care Alliance Proton Therapy - ProCure</td>
<td>Seattle, WA</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>University of Florida Proton Therapy Institute</td>
<td>Jacksonville, FL</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>No</td>
<td>Maybe</td>
<td>TBD</td>
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<tr>
<td>University of Maryland Proton Treatment Center</td>
<td>Baltimore, MD</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>No</td>
<td>Maybe</td>
<td>TBD</td>
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<td>Scripps Proton Therapy Center</td>
<td>La Jolla, CA</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>May 1-2</td>
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<td>OKC, OK</td>
<td>Y</td>
<td>Acceptable (cyclotron)</td>
<td>N/A</td>
<td>TBD</td>
<td>Yes $ TBD</td>
<td>500</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>May-June</td>
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<tr>
<td>Mayo Foundation</td>
<td>Rochester, MN</td>
<td>N</td>
<td>TBD (synchrotron)</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>No</td>
<td>No</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td><strong>Existing Facilities</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tri-University Meson Facility (TRIUMF)</td>
<td>Vancouver, CAN</td>
<td>N</td>
<td>Acceptable (cyclotron)</td>
<td>Yes $750</td>
<td>No</td>
<td>4x/year</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
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<tr>
<td>Slater Proton Treatment and Research Center at Loma Linda University Medical Center (LLUMC)</td>
<td>Loma Linda, CA</td>
<td>Y</td>
<td>Acceptable (synchrotron)</td>
<td>Yes $1,000</td>
<td>No</td>
<td>1000</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
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<tr>
<td>Mass General Francis H. Burr Proton Therapy</td>
<td>Boston, MA</td>
<td>N</td>
<td>Acceptable (cyclotron)</td>
<td>Yes $1,000</td>
<td>No</td>
<td>&lt; 800 hours, at capacity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>NASA Space Radiation Lab (NSRL)</td>
<td>Brookhaven, NY</td>
<td>Y</td>
<td>Acceptable (synchrotron)</td>
<td>Yes $4,700</td>
<td>No</td>
<td>&gt; 1000 hours</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Indiana University Cyclotron Facility</td>
<td>Bloomington, IN</td>
<td>N/A</td>
<td>Reference</td>
<td>Yes $820</td>
<td>N/A</td>
<td>2000 hours</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Beam size, dosimetry, flux, fluence, uniformity; **location, safety training, regulations, scheduling, payment, hazardous material handling, shipping, contracts, ITAR, etc...

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Summary

• NEPP is an agency-wide program that endeavors to provide added-value to the greater aerospace community.
  – Always looking at the big picture (widest potential space usage of evaluated technologies and NEPP products).
  – We look to the future by learning from our past.
• We’ve provided a developing roadmap as well as few general interest items.
• Next NEPP Workshop planned for June 23-26 2015.
  – Will be a mix of traditional June meeting plus CubeSat focus.
  – On-site open to U.S. only.
  – Web access available to international participants.

https://nepp.nasa.gov