Decline in radiation hardened microcircuit infrastructure

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## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ASIC</td>
<td>Application Specific Integrated Circuit</td>
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<tr>
<td>CDH</td>
<td>Central DuPage Hospital Proton Facility, Chicago Illinois</td>
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<tr>
<td>CNL</td>
<td>Crocker Nuclear Lab</td>
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<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
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<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>HUPTI</td>
<td>Hampton University Proton Therapy Institute</td>
</tr>
<tr>
<td>IBM</td>
<td>International Business Machines</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<tr>
<td>IUCF</td>
<td>Indiana University Cyclotron Facility</td>
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<tr>
<td>ITAR</td>
<td>International Traffic in Arms Regulations</td>
</tr>
<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratories</td>
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<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>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<tr>
<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
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<tr>
<td>NSREC</td>
<td>Nuclear and Space Radiation Effects Conference</td>
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<tr>
<td>NSRL</td>
<td>NASA Space Radiation Laboratory</td>
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<tr>
<td>ProCure</td>
<td>ProCure Center, Warrenville, Illinois</td>
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<tr>
<td>SEE</td>
<td>Single Event Effect</td>
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<tr>
<td>SEU</td>
<td>Single Event Upset</td>
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<tr>
<td>TRIUMF</td>
<td>Tri-University Meson Facility</td>
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<tr>
<td>UCD</td>
<td>University of California at Davis</td>
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</table>
Abstract

- Two areas of radiation hardened microcircuit infrastructure will be discussed:
  - The availability and performance of radiation hardened microcircuits, and,
  - The access to radiation test facilities primarily for proton single event effects (SEE) testing.
- Other areas not discussed, but are a concern include:
  - The challenge for maintaining radiation effects tool access for assurance purposes, and,
  - The access to radiation test facilities primarily for heavy ion single event effects (SEE) testing.
- Status and implications will be discussed for each area.
U.S. RADIATION HARDENED MICROCIRCUITS
Radiation Hardened Microcircuits - Foundries

• Well known decline in number of U.S. manufacturers of radiation hardened microcircuits:
  – From 20+ in 1990 to a handful in 2015.

• Many of the existing suppliers utilize a “foundryless” model where they are either:
  – A design house using a 3rd party fabrication facility, or,
  – Upscreen parts while adding radiation mitigation approaches (shielding, supervisory control, etc…)

• Changes to ITAR (U.S. State Department to Commerce) should ease access to these products for non-U.S. entities not on restricted list.
Foundries - Current Concern

• The cost of operating a dedicated state-of-the-art foundry is in the $Billions.
  – Using a commercial fabrication facility (like IBM) as front end for silicon die with radiation hardened library development (intellectual property, IP) and a Military/Aerospace vendor as the back end (packaging, test) has been the working plan.
  – This is similar to European Space Agency (ESA) approach with ST Microelectronics, for example.

• Many future radiation hardened standard product and Application Specific Integrated Circuit (ASIC) plans were based on the use of the former IBM foundry that is now GlobalFoundries (non-U.S. owned).
  – While the use of non-U.S. foundries/products is common for NASA missions, the U.S. government, in general, is concerned over access to a U.S. foundry.

• U.S. Government is reviewing options at this time.
  – NASA may be affected indirectly for future standard product access, but does not develop many ASICs requiring advanced technology nodes.
Radiation Hardened Microelectronics – More COTS?

• The underlying challenge:
  – Traditional radiation hardened electronics are multiple technology generations behind the commercial alternatives:
    • e.g., radiation hardened field programmable gate array (FPGA): 65nm feature size
    • Current state-of-the-art commercial FPGA: 20nm feature size. This is 3-4 generations more modern.
  – As technology has scaled, the power and volume versus performance metrics are improved – faster, smaller, more highly integrated, lower power.

• While NASA’s been a user of commercial parts since the 1970’s, these modern, very complex parts may require large amounts of additional mitigation for radiation sensitivities and evaluated for reliability challenges.
  – Modern system design mixes radiation hardened devices (“failsafe safing”) with high-performing COTS devices.
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.

- Ad hoc U.S. government team formed to investigate options.
  - Existing proton SEE test facilities (North America).
  - Explore access to newer proton cancer therapy sites.

- Study began in 2014-Oct.
Existing North American Proton Facilities

- **Tri-University Meson Facility (TRIUMF) – Vancouver, Canada**
  - Challenges with “border crossing,” limited “cycles” of availability
    - *TRIUMF is working with US State Department for easier access and hardware 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, and,
- **Loma Linda University Medical Center (LLUMC) and NASA Space Radiation Laboratory (NSRL)**
  - Have pulsed beam structures and other technical considerations.
Ad Hoc “Team” Plan/Status – 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
  ☐ Underway

☑ Work logistics of access
  ☐ Underway

• Determine guidelines for usage of these sites
  – Goal is to discuss at IEEE Nuclear and Space Radiation Effects Conference in Boston, MA in July.

• Recommendations for modifications and longer term access.
  – TBD

Assumption: Facilities will have available 300-500 hours/year each (weekends).

Multiple facilities required to replace IUCF in the near term.
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.*
  – Independent dosimetry required for SEE testing – flux, fluence and uniformity.
  – Beam intensity control: translation between SEE test parameters and tumor delivery.
  – Beam stops required (therapy “stops” beam in patient).
  – Radiation dose limits may impact some higher fluence tests.
  – Remote-controlled movement of test article mounting stage may not exist at all sites – time hindrance.

• Logistics
  – Access
  – Scheduling
  – Cost

*Testing at Cadence Health Proton Center, Warrenville, IL USA*
Background: Proton Beam Delivery

• There are two types of facilities being used for proton therapy:
  – Cyclotrons, and,
  – Synchrotrons.

• In addition, there are three types of beam delivery methods.
  – Scatter,
  – Wobble/uniform scan, and,
  – Pencil beam scan.

• *IUCF was a cyclotron and utilized a scatter beam delivery system.*
  – *Other options require thought and consideration for possible use.*
# 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>
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<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>
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<td>Maybe</td>
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<td>Maybe</td>
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<td>TBD</td>
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<td>Maybe</td>
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<td>$750</td>
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<td>4x/year</td>
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<td>Acceptable (synchrotron)</td>
<td>Yes</td>
<td>$1,000</td>
<td>No</td>
<td>1000</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Acceptable (cyclotron)</td>
<td>Yes</td>
<td>$1,000</td>
<td>No</td>
<td>&lt; 800 hours, at capacity</td>
<td>Yes</td>
<td>Yes</td>
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</table>

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

Deliverable to NASA Electronic Parts and Packaging (NEPP) Program to be published on nepp.nasa.gov originally presented by Kenneth A. LaBel at the European Space Research Institute (ESRIN) Trilateral Face-to-face (F2F) Working Group Meeting, Frascati, Italy, May 22, 2015.
Proton Takeaway Chart

• Rules of thumb
  – All proton cancer therapy sites are usable for static tests, parts that are fairly proton-SEU tolerant, and destructive tests.
    • Cyclotron, synchrotron
    • Any of the beam delivery modes (scatter or scan)
  – Timing dependent tests (dynamic operations) especially on very proton sensitive devices require careful thought for using other than an IUCF-like beam (a cyclotron with a scatter mode).
    • Further work is needed to evaluate useful nature of scan beam delivery.
  – Guideline development will be a critical deliverable by this team.
    • Expect to have a version available at IEEE Nuclear and Space Radiation Effects Conference
      – Boston, MA. USA – July 13-17, 2015.

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Protons – The Future

- Access/contracts/technical logistic “headaches” for cancer centers must be minimized to allow widest use for radiation effects research.
  - We are NOT their prime customer.
  - Long-term access hinges on three items:
    - Minimum invasiveness of our community on cancer therapy sites (technical, logistics),
    - Business model (for cancer therapy sites), and,
    - Medical usage not expanding to use “spare time” – insurance and doctor access are current limits, but may be changing.
QUESTIONS?