High Power 650 MHz Magnetron RF Power Source

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Overview - Technology Roadmap for High-power X-ray source for Medical Device Sterilization

- Fabricate and assemble a prototype 1.6 MeV compact SRF system to validate the integration of four enabling technologies
- Superconducting RF (SRF) is the technology of choice for today’s discovery science accelerators
- This project will demonstrate SRF’s suitability for industrial applications such as medical device sterilization

Poster 15J regarding RF Source Efficiency
Nonproliferation

Presently, X-rays represent about 1% of the medical device sterilization market whereas Co-60 services 40-50%.

• However, over 7 new X-ray facilities have been announced and will become operational in the next two years.

• Capacity issues in the medical device sterilization market are driving new interest in alternative technologies.

• Co-60 market is tight, leading to delays in resourcing and price increases. Requires yearly resourcing due to 12% decay per year.

• Accelerator manufacturers are booked at least for the next two years.

• **Important note: Technical availability nor concerns regarding radioisotopes did not drive change. The shortage of cobalt-60 is the driver.**
Project Overview, Goals, Deliverable

Goal: Fabricate and assemble a prototype 1.6 MeV compact SRF system to validate the integration of:

1. Integrated electron gun
2. Conduction cooling & Cryocoolers
3. Nb\textsubscript{3}Sn coating
4. Low-heat loss RF coupler

Efficient, high-power X-ray source for medical device sterilization

- 1 MCi of Co-60 produces ~ 15 kW of power
- X-rays are essentially a direct replacement for Co-60 irradiation
- ~ 120 kW of electron beam power to equal 1 MCi of Co-60
- Validation of this design is the final step before a first article of 7.5 MeV, 200 kW.
Progress to Date

- Cryocoolers are on-hand
- RF power supply on-hand & being commissioned
- Cavity fabricator has been selected and materials delivered
  - Due to be delivered Aug 1, 2022
  - Another project has successfully coated a 1-1/2 cell cavity with Nb$_3$Sn
- RF Coupler PO anticipated Jan 2023
- Final Cryostat design is being completed.
- Test Cave being assembled
Challenges - Integrated Electron Gun

Integrated gun injects directly into cavity with no transport line

See for instance: Burrill, et.al., Processing and Testing of the SRF Photoinjector Cavity for bERLinPro, IPAC2014, WEPRI005
Issues and challenges of the internal injection and cavity design

- Forming of the short bunches (without tails) having small transverse emittance;
  - Gridded cathode emission
  - Optics optimization
- Cathode evaporation, reducing the cavity $Q_0$
  - Small cathode size
  - Choice of the cathode type with acceptable evaporation rate
- Black Body radiation - heat flow from the cathode to the cavity;
  - Optics optimization
  - Relatively low-temperature dispenser cathode
  - Small cathode size and heater power
  - Shielding, good thermal insulation
  - Cathode positioning
- The gun grid heating, current intercept;
  - Optics optimization
  - Shadow (masked) cathode emitter
- Coupling between the gun resonator and SRF cavity
  → Additional RF power to compensate field induced by SRF cavity;
  → Possible beam current modulation by HOM modes → HOM self excitation;
Cathode misalignment tolerance

- MICHELLE studies related to the effect of cathode misalignment on the electron beam parameters have been carried out
- Acceptable parameters changes and no additional losses on the cavity walls

The technical engineering design of the cathode is currently under development in collaboration with the vendor.

The accuracy and tolerance analysis including:
- the cathode-grid gap precision
- grid tilt and deformation due to heating
- cathode-grid assembly adjustment to the cavity iris plane

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th>+ 0.2 mm</th>
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<tbody>
<tr>
<td>$\sigma_E$, %</td>
<td>1.9</td>
<td>2.02</td>
</tr>
<tr>
<td>$\sigma_{\text{phase}}$</td>
<td>6.8</td>
<td>6.75</td>
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<tr>
<td>$E_{\text{p}}$, mm*mrad</td>
<td>5.27</td>
<td>5.23/6.55</td>
</tr>
<tr>
<td>Back bomb., W</td>
<td>0.23</td>
<td>0.29</td>
</tr>
<tr>
<td>Grid losses, W</td>
<td>0.33</td>
<td>0.32</td>
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</tbody>
</table>
Manufacturability of the grid

\[ T = 293K \]

Old grid

<table>
<thead>
<tr>
<th>Grid</th>
<th>Losses, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old</td>
<td>0.35</td>
</tr>
<tr>
<td>New</td>
<td>0.6</td>
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</tbody>
</table>

New grid
**Adjustments due to grid modification**

**Old grid**

![Old grid diagram]

\[ T = \text{ambient} + 283^\circ \text{K} \]

**New grid**

![New grid diagram]

\[ T = \text{ambient} + 635^\circ \text{K} \]

**New materials**

![New materials diagram]

\[ T = \text{ambient} + 276^\circ \text{K} \]
Remaining work

- Layout of beamline to dump is ongoing
- Completion of design of cryostat & procurement
- Processing, cleaning, testing, coating of cavity upon receipt
- Assembly of components
Conclusion

- The prototype SRF accelerator is an important element in the path towards high-power alternative technologies for Co-60 replacement for medical device sterilization.
- First integration of SRF technologies and conduction cooling into a prototype compact accelerator.
- The validation of this SRF design is the final step before a first article of 7.5 MeV, 200 kW.
Thank you