Office of Nonproliferation Research and Development

Radiological Source Replacement Program Review Meeting

RSR2010

Compact Megavolt Electronic Gamma Source

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FY10 New-Start Project (October, 2009)

Sandia National Laboratories

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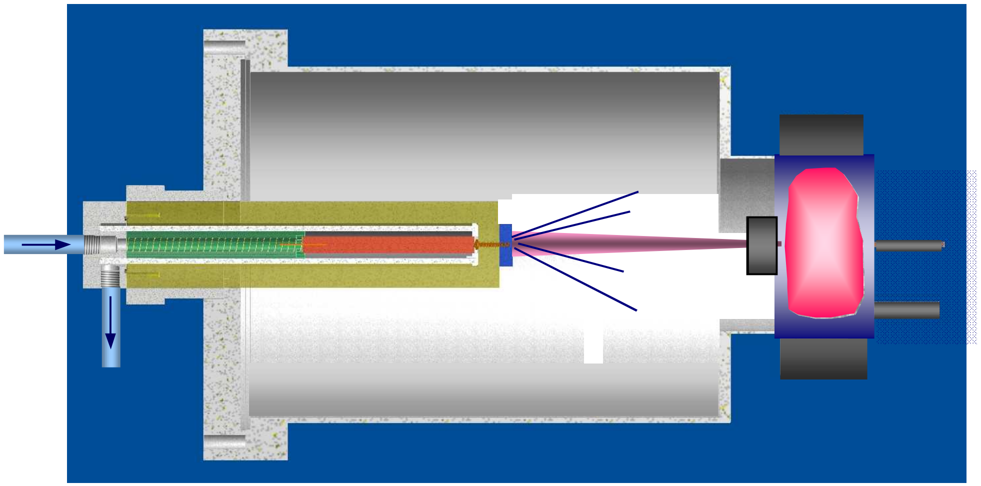
FY10 Budget: $450K

Compact Megavolt Electronic Gamma Source

Project Overview

- **The 2009 RSR GOR document states the need for replacing high activity radiological sources presently used in commercial applications.**
- **We are developing a compact mono-energetic gamma generator to replace isotopic gamma sources.**
  - **(D, γ) nuclear reactions**
  - **0.5-1.0 MeV photon energies**
  - **D^+ ion source and pyroelectric crystal accelerator**
  - **Dielectric fluid heating/cooling**



Main Components:

✓ D^+ Ion Source & E x B Mass Filter
✓ Pyro-Acceleration System
✓ Gamma Production Target

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Compact Megavolt Electronic Gamma Source

Goals

- Develop an accelerator-based gamma source to replace radiological sources.
- Explore the functionality of the source relevant to user needs.

Technical Approach

- Exploit low-energy (D, γ) nuclear reactions to generate megavolt-energy gammas (nature's nuclear amplification).
- Implement an efficient ion source and E x B mass filter to extract atomic D^+ ions.
- Develop advanced powering system to accelerate D^+ beam onto a production target for generating gammas.

FY10 Deliverables

- Demonstrate MeV-energy gamma production from prototype γ-source.
- Technical report on system design and operational performance characteristics.

Capability Improvement Relevant to the Nonproliferation Mission

No *electronic mono-energetic gamma source* is available today to replace radiological gamma sources.

Existing megavolt linear accelerators (linacs) produce broad spectrum Bremsstrahlung radiation, are large and heavy, have high maintenance and operational costs, and generate large unwanted dose due to low-energy photons.

A compact megavolt gamma generator would enable a viable low-cost, high-performance solution for replacing radiological sources used in commercial applications, while significantly reducing the RDD threat in National Security.

Compact Megavolt Electronic Gamma Source

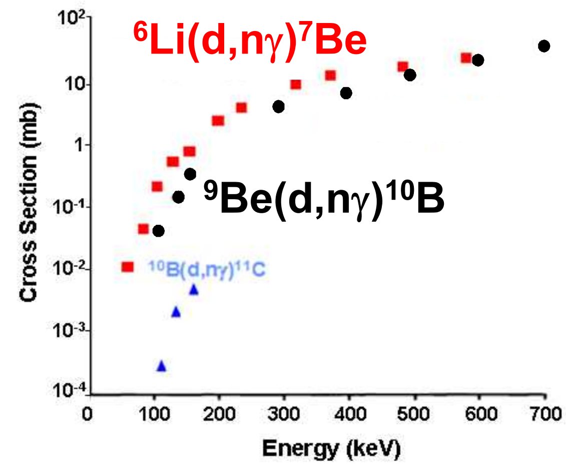
Technical Approach: *Nuclear Reactions*

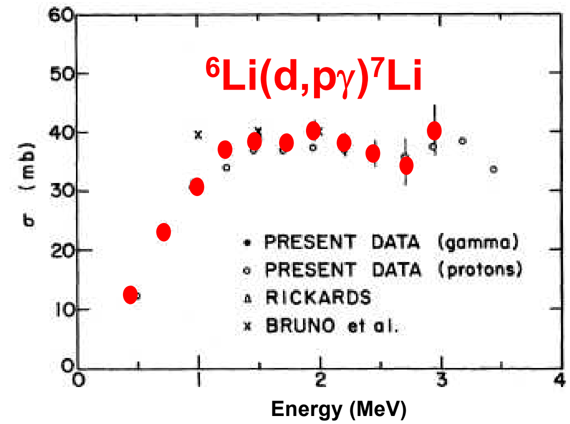
Megavolt-energy gammas are produced by low-energy (D,γ) nuclear reactions.

$$D + {}^{9}Be \longrightarrow {}^{10}B + n + \gamma \text{ (410 keV, } \underline{\textbf{718 keV}}, \underline{\textbf{1.03 MeV}}, \text{ 1.44 MeV, 2.87 MeV)}$$

$$D + {}^{6}Li \rightarrow {}^{7}Be + n + \gamma \text{ (430 keV)}$$
$$D + {}^{6}Li \rightarrow {}^{7}Li + p + \gamma \text{ (480 keV)}$$

- **Both reactions above also produce neutrons.**
  - ${}^{9}Be(d,n\gamma){}^{10}B$ Q = 4.36 MeV E_n = 1.0-4.3 MeV
  - ${}^{6}Li(d,n\gamma){}^{7}Be$ Q = 3.38 MeV E_n = 2.5-2.9 MeV
- **A reaction such as ${}^{10}B(n, \alpha\gamma){}^{7}Li$ can be used to convert the neutrons to gammas.**



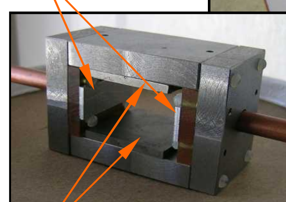


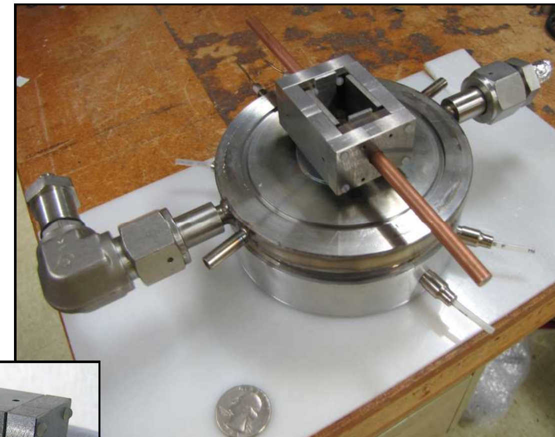
Cross section data from F.E. Cecil, R.F. Fahlsing and R.A. Nelson, *Nuclear Physics* A376 (1982) 379-388

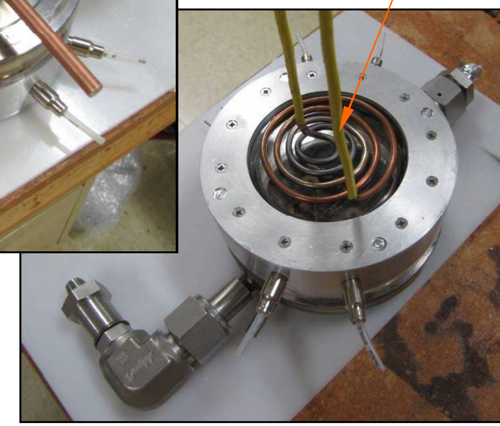
National Nuclear Security Administration

Technical Approach: *Ion Source and E x B Mass Filter*

- 1 kW, 13.5 MHz RF-driven plasma ion source produces >90% atomic D^+.
- D^+ beam is extracted at low voltage.
- A permanent magnet E x B mass filter removes molecular ions and secondary electrons.

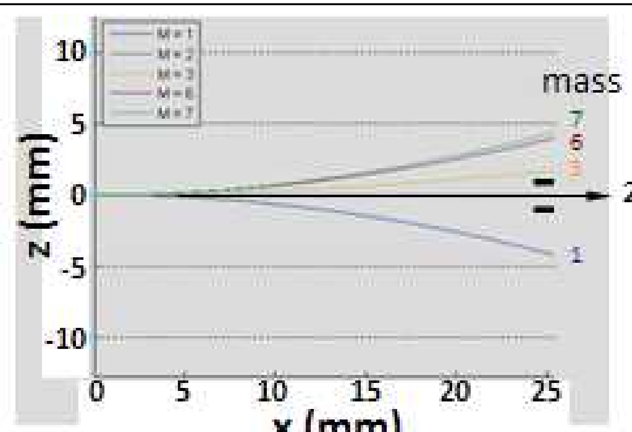






Mass Filter Design Modeling

- Extraction voltage: 1 kV
- Magnetic field strength: 2 kG
- Electrostatic deflection voltage: +/- 789 V
- Aperture diameter: 2 mm



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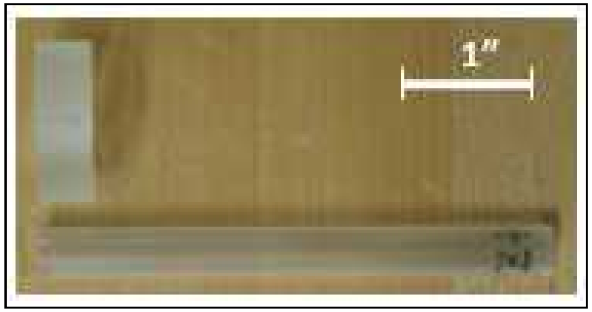
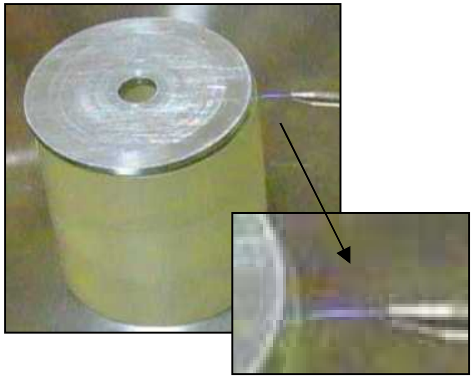
Technical Approach: *Pyro-Acceleration System*





- **Pyroelectric crystals are used to provide the acceleration potential without a large external HV power supply.**
- **Other groups have explored pyroelectric crystals for X-ray and neutron production.**
- **Single 1" x 1" $LiTaO_3$ pyroelectric crystals have recently achieved voltages up to 300 kV when heated or cooled in vacuum.[1]**

Spontaneous polarization occurs when a pyroelectric crystal is heated or cooled.

The charge on the crystal surface is given by

$$Q = \gamma A \Delta T$$

Pyroelectric coefficient (γ) = 0.19 nC/cm^2/^{o}K for $LiTaO_3$

For 3 cm-ϕ crystal and $\Delta T = 100^o$ …

Predict Q ~ 0.1 μA

Best measured[2] to date, Q ~ 10 nA (80 keV)

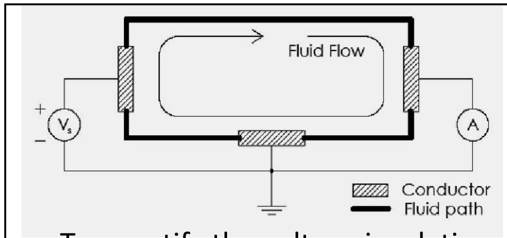
[1]W. Tornow et al., Jour. Applied Phys. 107, 063302 2010

[2]V. Tang *et al.*, Rev. Sci. Instr. **78**, 123504 2007

Compact Megavolt Electronic Gamma Source

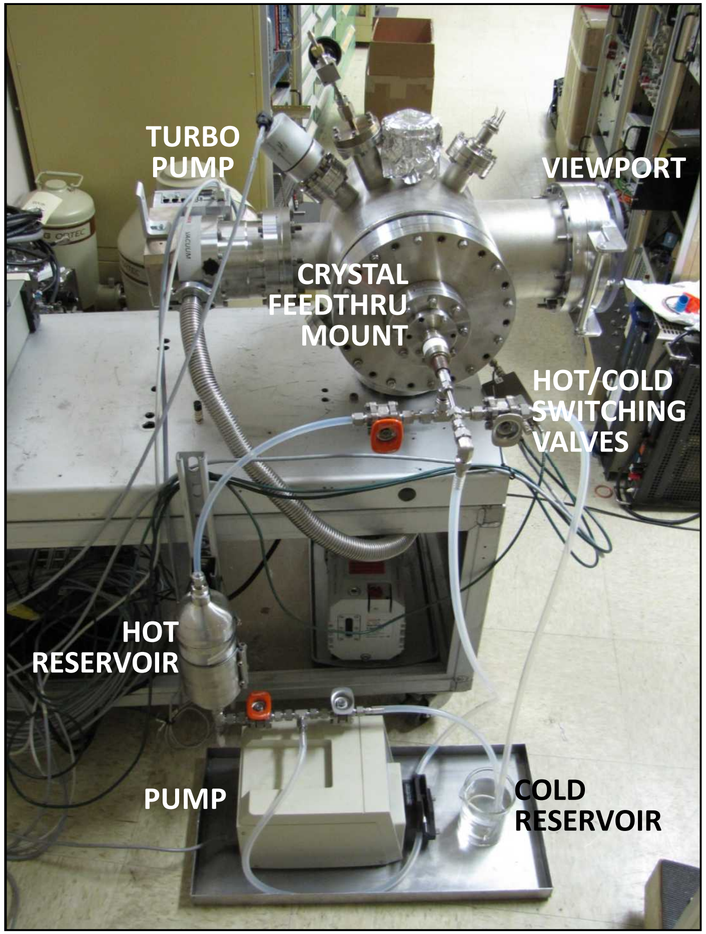
Technical Approach: *Pyro-Acceleration System*

- **A heater/chiller flowing a dielectric fluid will be used to regulate the pyroelectric accelerator system.**



Dielectric Fluid Leakage Current Experiment

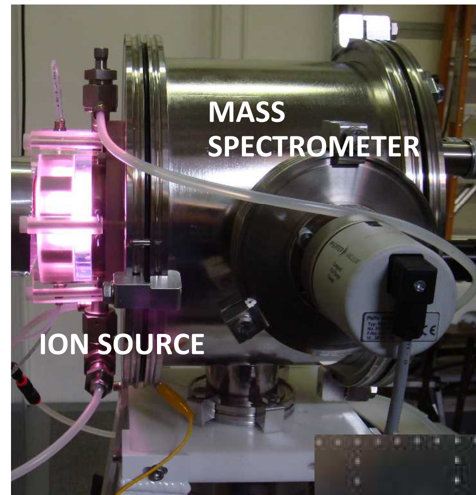
- To quantify the voltage insulation properties of a flowing dielectric fluid, we measured the current across a floating conductor and ground.
- The floating conductor is connected directly in the fluid path so that any charge stripped by the fluid from the high voltage conductor gets read as leakage current in the ammeter.
- The experiment was done with Fluorinert and transformer oil.
- The leakage current was found to be less than 10 pA.

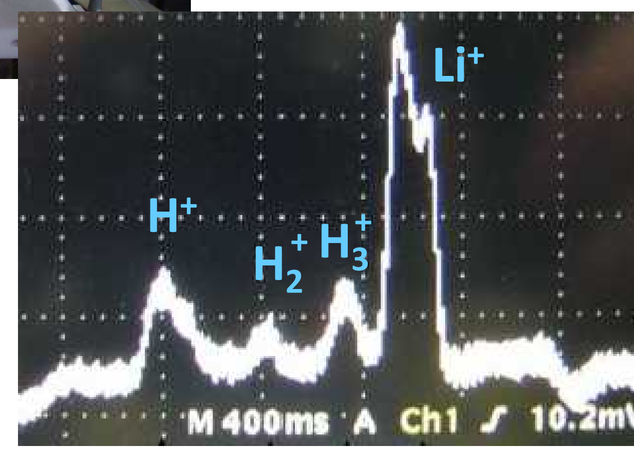


- **We are exploring ways to increase the available pyroelectric current (larger diameter crystal, larger ΔT, higher temperature operation, etc.)**

Technical Approach: *Gamma Production Target*

- **Targets:**
  - **Solid or beam loaded Li-6**
  - **Solid Be-9 metal**
- **Beam power density will be optimized for the best gamma yield and target lifetime**
- **Ion species and fractions in the beam are measured with a custom mass analyzer.**

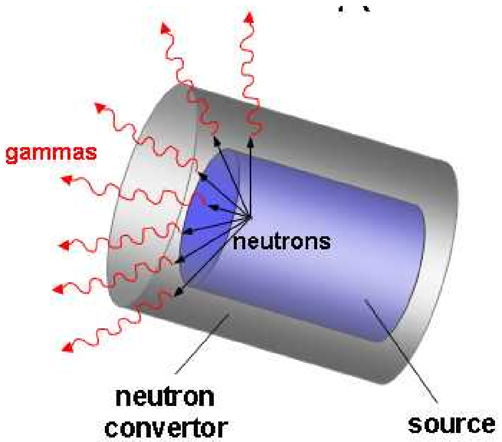




Screenshot of mass profile in H/Li plasma

LiF **LiCl** **Li_2CO_3** **Li metal** **Be metal**

Technical Approach: *Neutron Convertor*

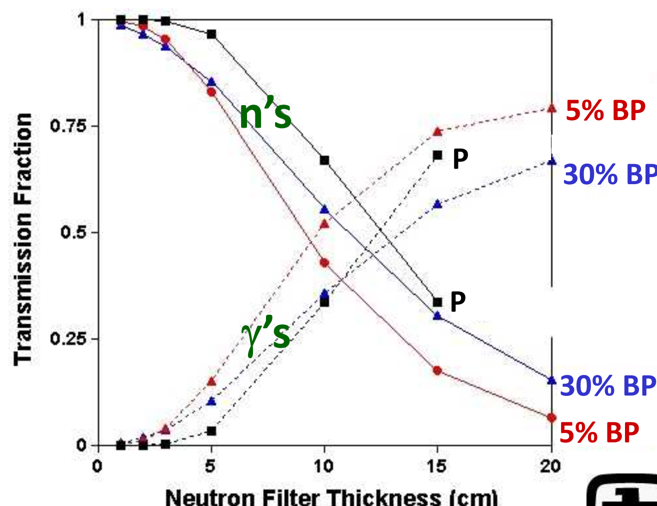


- D $\rightarrow$ ^{6}Li and D $\rightarrow$ ^{9}Be produce neutrons.
- A neutron convertor can be used filter the neutrons and convert them to gammas.

$$n + {}^{10}B \longrightarrow {}^{11}B^* \longrightarrow \alpha + {}^{7}Li + \gamma \text{ (480 keV)}$$

MCNPX Modeling:

- Compare poly (P), 5% borated poly (5% BP), and 30% BP
- Gammas from n $\rightarrow$ ^{10}B and thermal neutron capture by hydrogen in poly
- Best performer: 5% BP
- Preliminary results suggest layering materials would achieve optimum neutron filtering and convertor thickness.



Interactions

- The Radiation Oncology Department at University of California San Francisco (UCSF) has expressed interest in developing replacement gamma sources for radiotherapy.

- UCSF has also expressed interest in teaming with SNL to explore the functionality of the electronic gamma sources to evaluate their operational performance and adaptability into current medical instrumentation.

Compact Megavolt Electronic Gamma Source

Technical Challenge	Mitigation Strategy
Achieving 300-400 kV acceleration potential	Stacking thin crystals in series or implementing single long crystals
Preventing voltage breakdown	Using dielectric insulating media
Heating the crystal rapidly and uniformly	Controlling thermal management by heating on all crystal surfaces
Increasing the available pyroelectric current	Using larger diameter crystals, larger temperature change in the crystal, multiple crystals, other pyroelectric materials, higher temperature operation (near Curie temperature)
Robust solid target	Beam-loaded target

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Future Work for the Remainder of the Project

FY10 –

- **Demonstrate gamma production from a prototype pyro-accelerated gamma source operating at >100 keV.**

FY11 –

- **Demonstrate gamma production from a prototype gamma source that can accelerate both D^+ and D^- in the heating and cooling phases.**

FY12 –

- **Demonstrate high yield gamma production from a prototype high current pyro-accelerated gamma source.**