Phase and Frequency Locked Magnetrons for SRF Sources

SBIR/STTR NP Exchange Meeting
Oct 1-2, 2012

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Outline of Presentation

- Introduction to Muons, Inc.
- Phase and Frequency Locked Magnetrons for SRF Sources (Fermilab Research Partner-subcontractor). This project is funded by a Phase II STTR grant from NP (DOE).
  - Description of Problem
  - Technical Approach
  - Current Status
  - Commercialization Plan

History of Muons, Inc.

- Muons, Inc. was founded in 2002 to participate in SBIR and STTR programs which fund research on muon beam cooling and on applications such as neutrino factories, muon colliders, and stopping muon beams.
- Muons, Inc. collaborates with 9 labs (ANL, BNL, Fermilab, JLab, LANL, LBNL, ORNL, PNNL, SLAC) and 9 universities (U. Chicago, Cornell, FSU, GWU, Hampton U, IIT, NCSU, NIU, ODU)
- Muons, Inc. and its collaborators have been responsible for a number of key inventions and innovations for muon colliders, and muon colliders have now become a very active field of research for future energy-frontier facilities for high-energy physics.

Engineering Services at Muons, Inc.

- We have become pretty strong in the RF business, with Mike Neubauer, Alan Dudas, Frank Marhauser, and Grigory Kazakevich as full-time RF staff.
- We have a new initiative using the SLAC ACE3P code to model complex and/or large RF structures
- Just completed a contract with JLAB to simulate dark currents in a realistic 8-cavity 12-GeV Upgrade cryomodule using ACE3P on supercomputers
- Accelerator-Driven Subcritical Reactors are our primary commercialization interest for magnetrons

Muons, Inc.

GEM*STAR can Eliminate W-Pu or SNF

Muons is partnering with ADNA Corp to develop a game-changing application of accelerator technology – designing and building a new form of intrinsically safe nuclear power called GEM*STAR (Green Energy Multiplier*Subcritical Technology for Alternative Reactors).

<u>Reduces Weapons-grade Plutonium (W-Pu) and Spent Nuclear Fuel (SNF) Storage Concerns!</u> GEM*STAR safely uses W-Pu or SNF (generated by traditional nuclear power plants and currently stored on a "temporary basis" around the country on the sites where it is generated with no permanent disposal plan presently available for it) to produce environmentally clean power. This technology can change unwanted nuclear materials into a valuable fuel for inexpensive carbon-neutral industrial processes and electricity production.

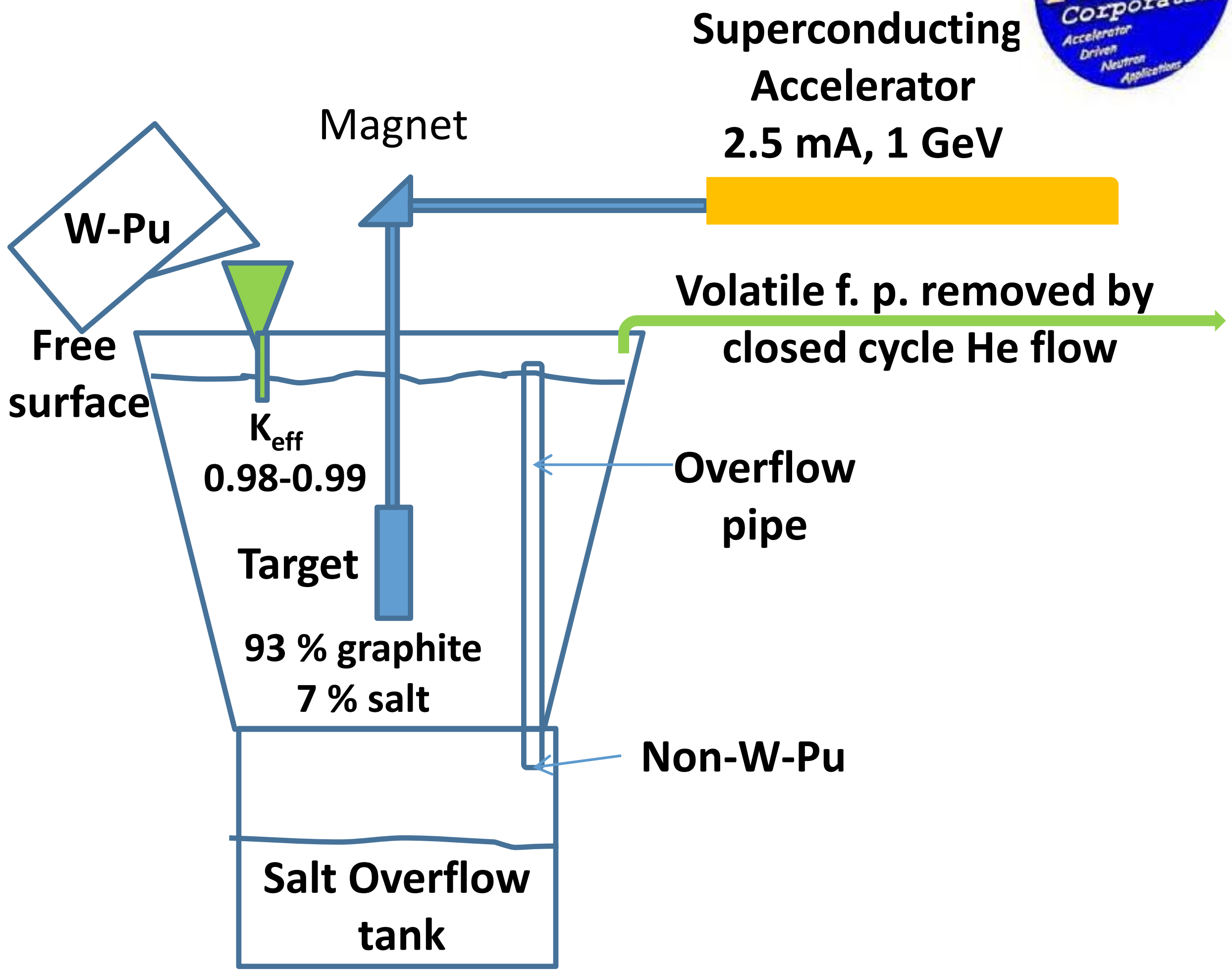
<u>No Possibility for Large Volatile Releases (as at Fukushima)</u>! GEM*STAR uses Molten-Salt fuel, derived safely and easily from W-Pu or SNF, which permits dangerous volatile radioactive elements to be continuously purged and safely stored.

<u>No More Chernobyls</u>! GEM*STAR reactors never contain the critical mass of material needed for an uncontrolled self-sustaining chain reaction.

<u>Major Nuclear Weapons Proliferation Impact!</u> Nuclear proliferation issues are avoided since the molten-salt fuel does not need to be enriched or reprocessed.

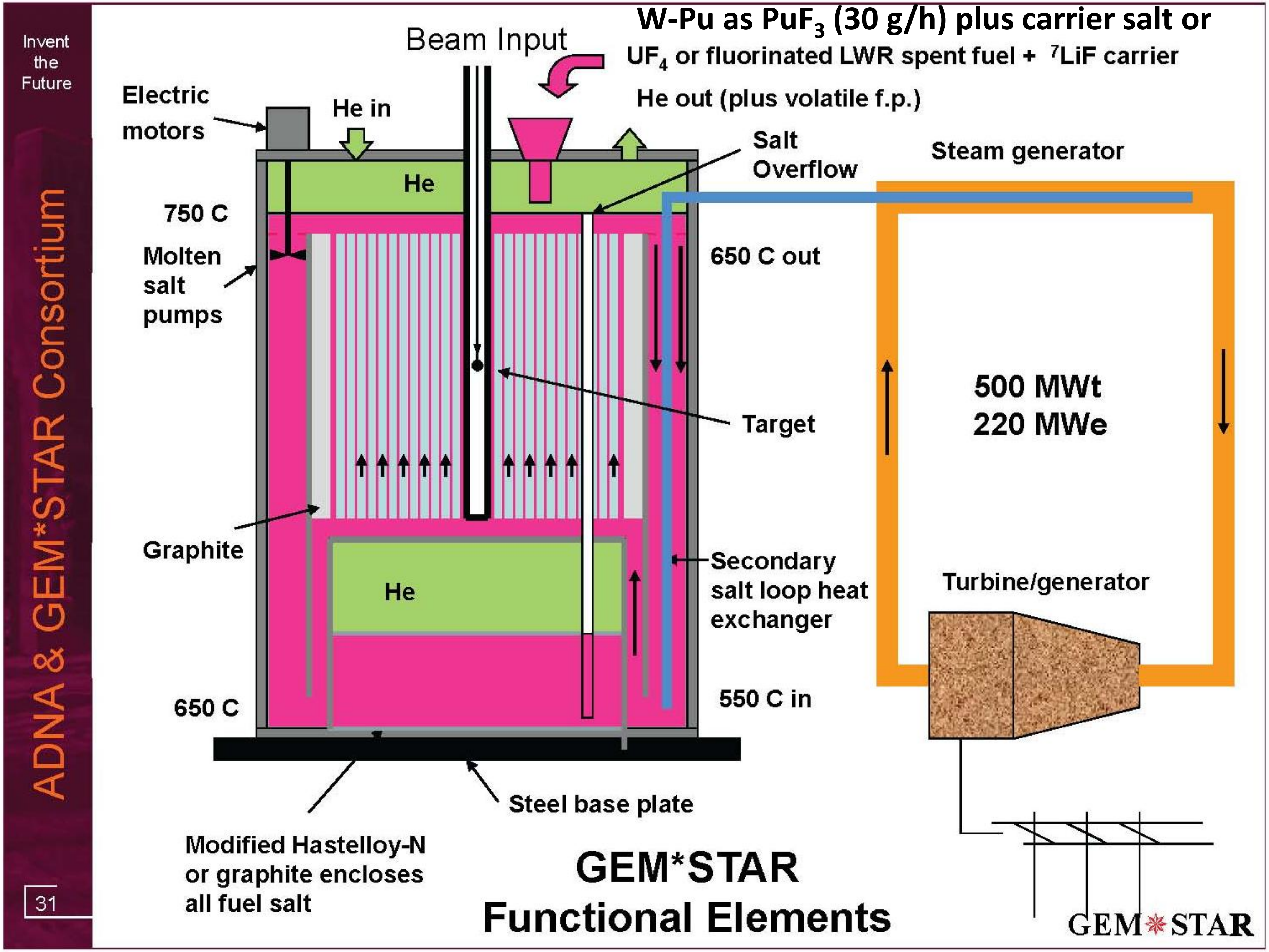
<u>GEM*STAR Adds Tremendously to U.S. Energy Independence and Emits No CO2!</u> Using this technology, the 75,000 tons of U.S. stored SNF can be reburned without reprocessing, MOX fuel preparation, or danger of future weapons use, and with delayed and reduced storage requirements. This SNF is sufficient to provide all (500 GW) U.S. electrical power for over a hundred years.

GEM*STAR Burns Weapons-Pu or SNF



Fission power 500 MWt

W-Pu as PuF_3 (30 g/h) plus carrier salt or UF_4 or fluorinated LWR spent fuel + ^7LiF carrier



GEM*STAR Functional Elements

The opportunity and the problem

- The opportunity is that magnetrons produce RF power for the lowest capital cost and operating cost and can operate at >90% efficiency.
- The problem is they are noisy, low Q sources:
  - Frequency pushing from power supply ripple and current fluctuation
  - Frequency pulling from load variations
  - Phase instability due to a cylindrically symmetrical resonant structure
- Great for a microwave oven and terrible for operating as a source for a high Q SRF cavity

Technical Approach in the NP SBIR

- Break the symmetry of the resonant structure for phase stability
- Provide for reasonably fast (ms level) and easy frequency adjustability.
- Partner early on with a commercial manufacturer of magnetrons
- Dual use application
  - Accelerators require frequency and phase locked operation
  - Phased array radar system requires only frequency adjustability of greater than 10% bandwidth.

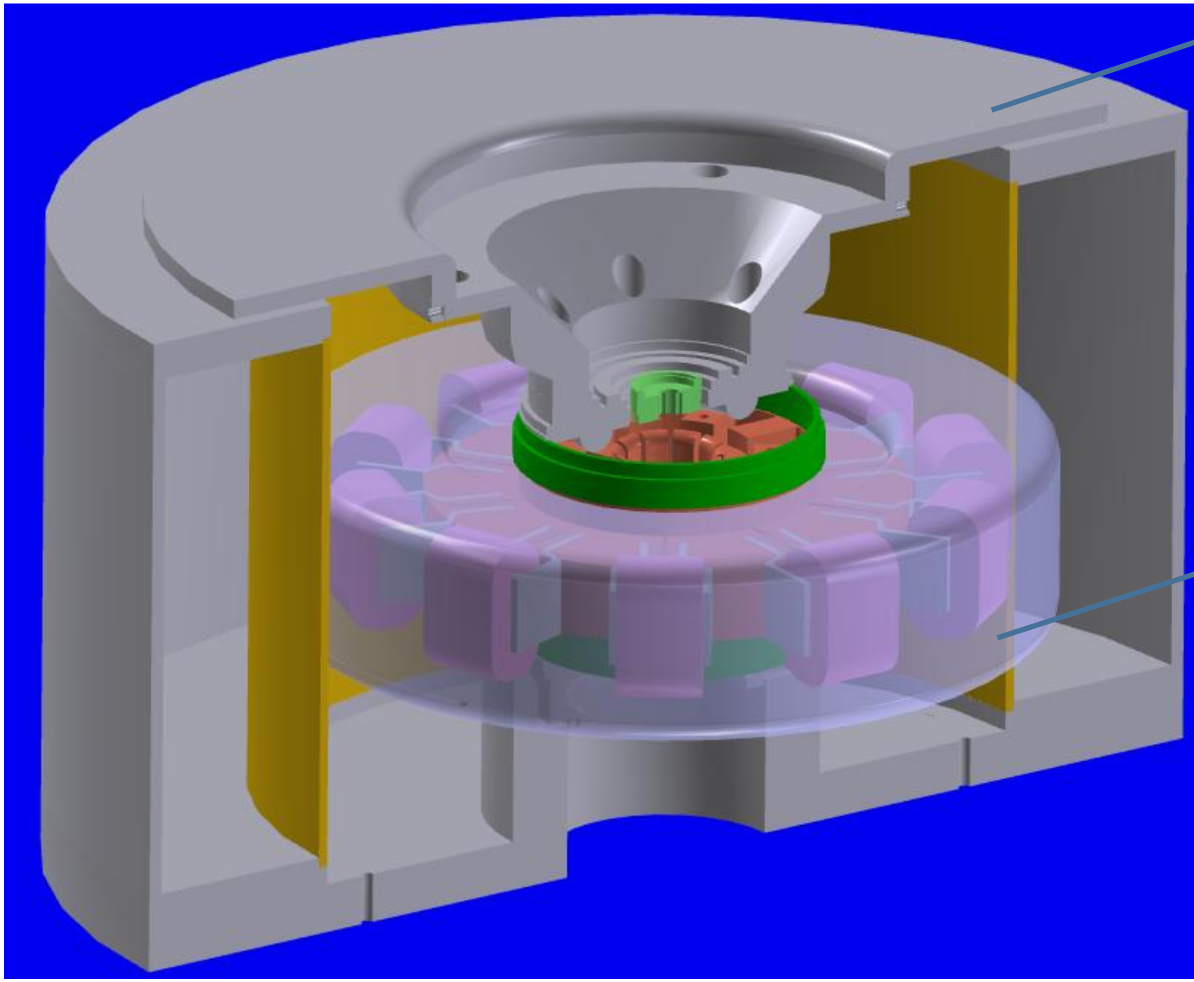
Technical Issues

- Find a suitable material that is vacuum compatible with bakeout temperatures of 500C.
- Determine a magnetic field operating point for the chosen material that
  - Minimizes losses and
  - Does not interfere with the magnetic field which operates the magnetron
  - And is not saturated by the magnetron magnetic field
- Design an electronic feedback circuit to vary the ferrite/garnet magnetic field to control the magnetron frequency relative to a standard. Straightforward task once the operating points are established

Phase II

- 1. Finding the right material - completed
- 2. Shielding the ferrite/garnet from the magnetron magnetic field – design completed ~ 6 months
- 3. Determine the optimum location for the ferrite – design completed ~ 6 months many iterations
- 4. Build and test a prototype to measure the magnetic fields and magnetron resonant circuit characteristics – in process
- 5. Building a magnetron – depends on the success of item 4.

Prototype Design being built



All gray areas are iron for the magnetic field of the magnetron

Shielding for the ferrite/garnet magnetic field

Optimum Location and Size of ferrite/garnet slab

Magnetron Resonant Cavity (10 total)

Ferrite/garnet biasing field

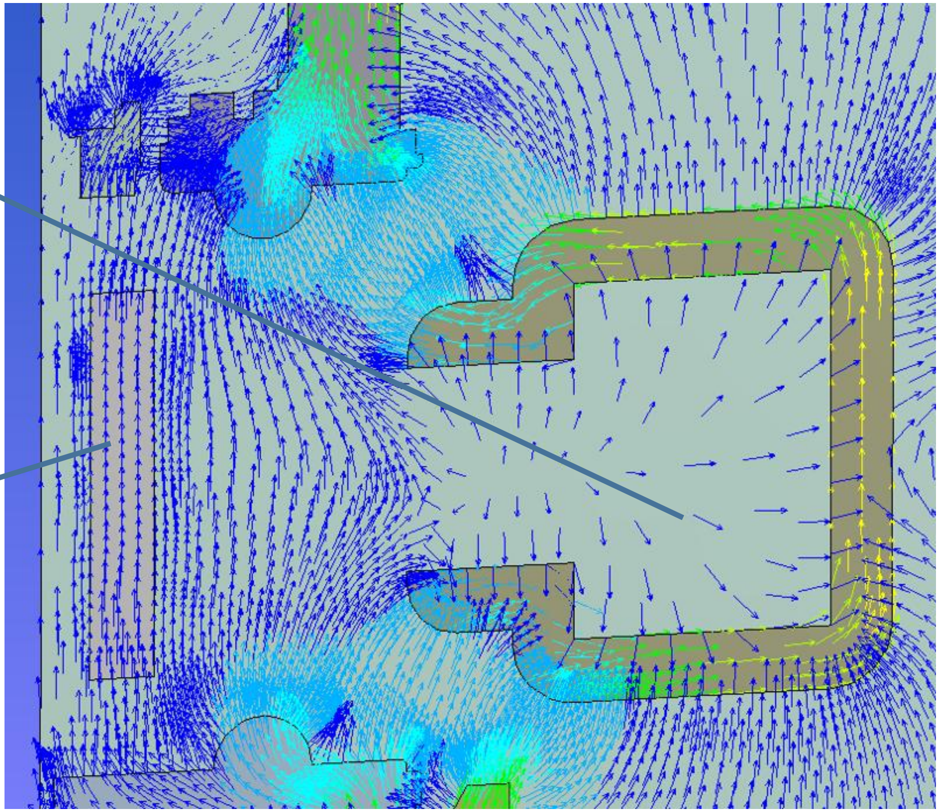
Coupling Slot to ferrite/garnet cavity

Ferrite/garnet cavity with a slab

Shielding the ferrite/garnet from the magnetron field – 3D ANSYS

Shielding Region for the ferrite

Uniform magnetic field in the interaction region



Collaboration with our manufacturing partner

- All stages of the design effort were completed with feedback from the engineers and experts at CTL L-3 as part of our contract with them.
  - The prototype structure we are building could be used in a final tube.
- Management Changes at L-3
  - CTL in Watsonville, CA is being absorbed into L-3.
  - The individuals we were interacting with are no longer part of L-3, but could become consultants.

Test Equipment Purchase and Extension request for Phase II

- We purchased the critical components from CTL L-3 to continue the testing of the prototype structure at Fermilab (Feb 2013).
  - Electromagnet and associated pole pieces.
- We requested an extension of the Phase II contract and received approval for a 6 month extension.

Commercialization Process

- The completion of the STTR research project consists of the construction and testing of a proof-of-principle prototype. The results will be published and reported to the DOE.
- Successful commercialization requires additional steps:
  – Engineering design of a commercial product
  – Manufacturing and Sales
- We can continue with L3 once the CTL move is complete. However, we are considering CPI (Communication and Power Industries).