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Rapid Cryogenic Layering for IFE Targets

Craig Halvorson, Ph.D.

James Sater, Ph.D.

Donald Bittner, Ph.D.

Schafer Laboratories

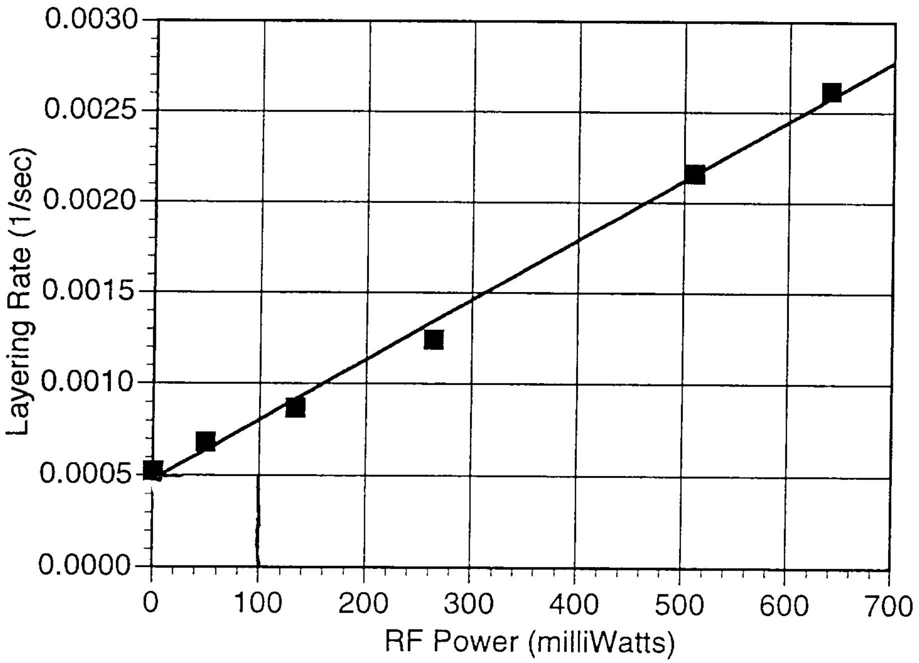
Rapid fuel layering

- Scale up of the cryogenic fuel layering process to IFE requirements:

Layering Period	Targets in Process	Process Maturity
8 hours	144,000	NIF baseline
30 minutes	9,000	One experiment
5 minutes	1,500	Not demonstrated
1 minute	300	Maybe not necessary

  - Rapid layering can reduce the tritium inventory and size of an IFE target factory.
- Conceptual design of an IFE reactor rapid layering system.
  - Examination of scaling issues.
  - Experiments and analysis required.
- Implementation of the experiments.
- Conclusions.

Rapid layering can minimize tritium inventory and target factory size.



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Native beta layering

Experimental results from E. Mapoles et. al. 1996.

An e^5 reduction in ice roughness in a particular cavity requires 650 mW RF power applied for 35 minutes.

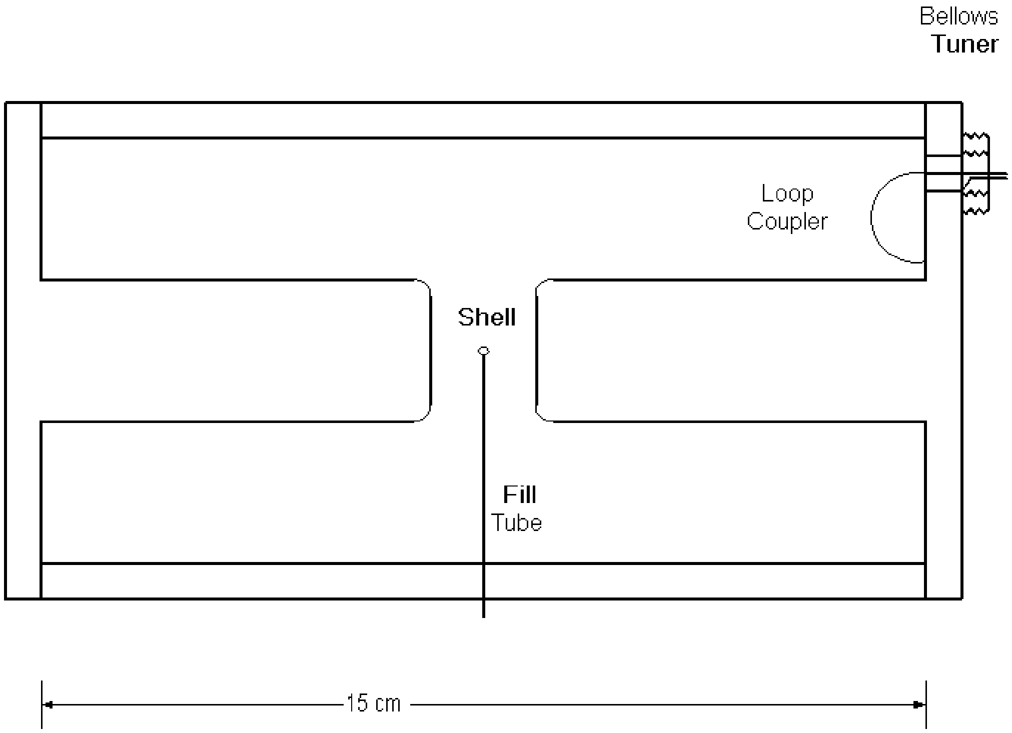
How much further can the layering time be reduced?

How much of the applied power is lost to parasitic absorption?

> Most: Native beta layering requires 50 mW/cc of DT ice.
>
> Significance: 1.3 liters of liquid He/hour evaporates to dissipate 1 watt, so parasitics must be minimized for best efficiency.

RF re-entrant cavity

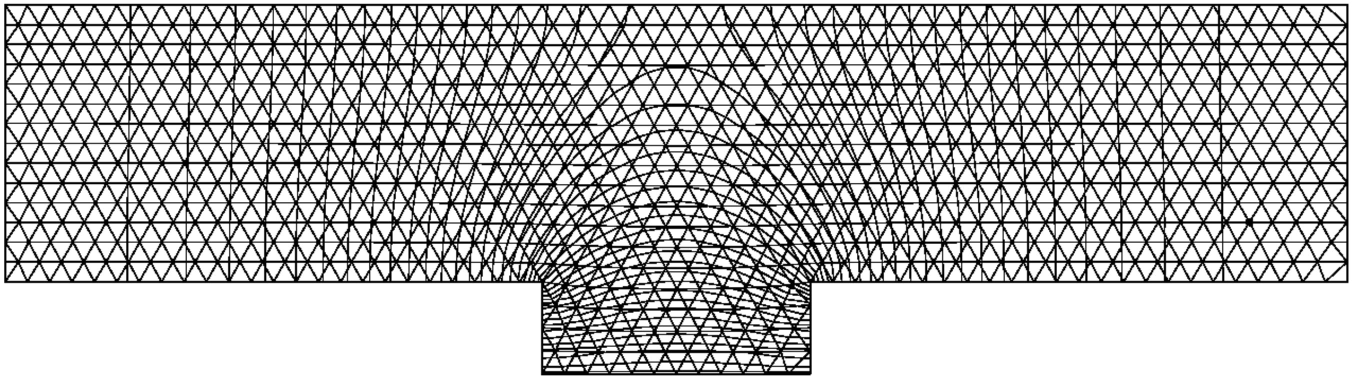
1 GHz re-entrant cavity: The loop generates a magnetic field, which induces a uniform, intense electric field in the gap.



The cavity shown is that used to generate the data on the previous slide.

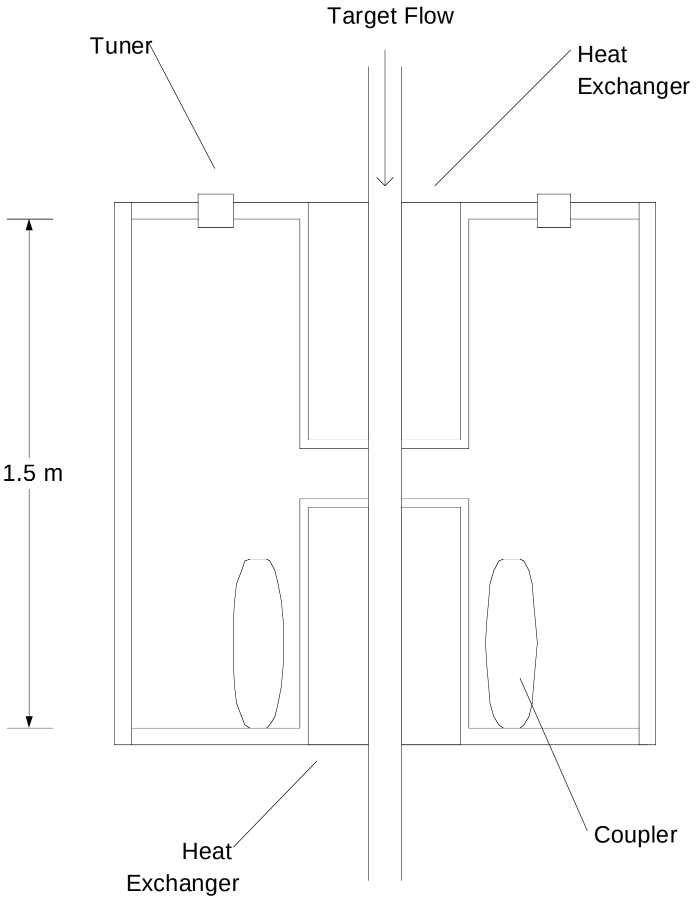
It is a half wave cryogenic cavity, and this general design is widely using in accelerators to produce intense, highly uniform electric fields. Typical linac cavities are coated with a superconductor to limit the cryo cooling requirements, and have highly engineered smooth surfaces to limit arcing due to field emission.

Superfish cavity model



- Electric field lines are shown against a coarse triangular mesh.
- This is a 2D slice through an axisymmetric cavity. The axis of symmetry is along the base of the T, where the target would be placed.
- Superfish can iteratively optimize the cavity geometry. The cavity model shown has not been optimized, for example by rounding edges.
- What is the field inside a metal coated shell?

Conceptual layout of a layering cavity for an IFE reactor

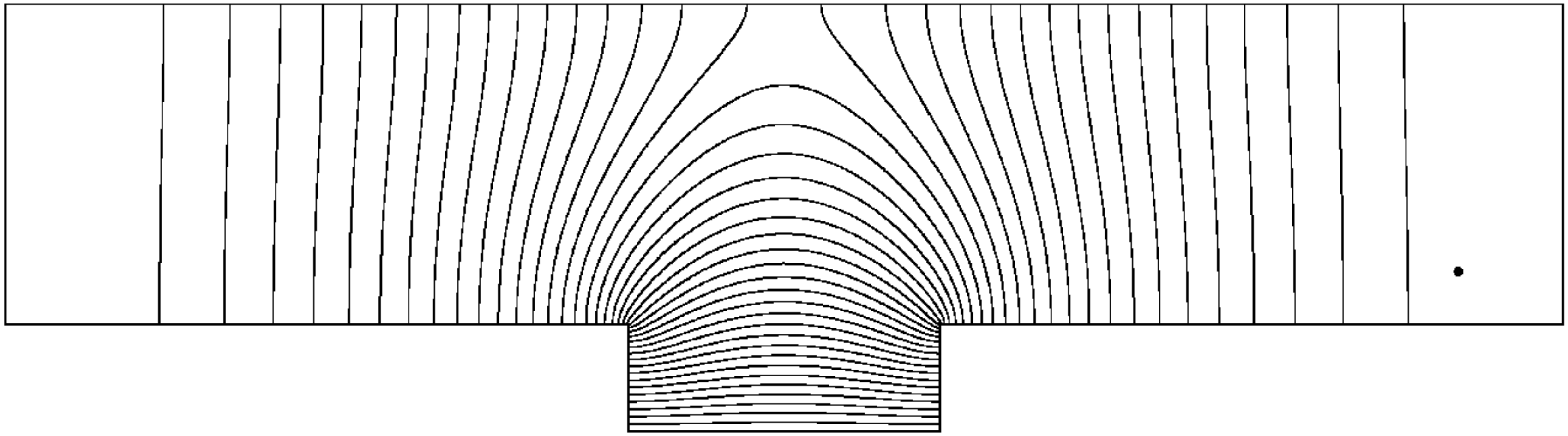


Strawman Scale Up Example:

Cavity length:	1.5 m
RF frequency:	100 MHz
Q:	3 x 10^5
Cavity wall:	Copper
Layering time:	10 minutes
Power into cavity:	750 W
Power into DT ice:	75 W
Targets in process:	3,000

It is important to control the parasitic losses; this lossy copper wall cavity would consume 1000 liters of liquid He per hour. Superconducting cavities achieve Q values of 10^10.

Field in an IFE reactor layering cavity



- The targets would travel along the base of the T. Note the excellent field uniformity there.
- The grid has been suppressed in this calculation. A fine grid was used.
- This cavity geometry has not been optimized; an optimized cavity would have rounded edges, and the top would have a bulge to further improve uniformity in the gap. Highly optimized linac cavities have a soft, “kidney bean” rounded profile.
- The drive point is the black dot on the right; it marks the center of the coupler loop.

Experimental data needed

1) Measure ice layer roughness on an IFE type encapsulated foam hemishell.
  - Possible smoother surfaces on ice layers grown on foam.
    - Many foam nucleation sites should reduce the crystallite size.
  - System impact: IFE fuel layering might be easier than we think.
  - Suggested Implementation: At Schafer Livermore using deuterium.

2) Measure the parasitic losses.
  - Measure the loss tangent of the shell.
    - System impact: determines shell heating, affects ice thermal stress.
  - Measure the power dissipated into the cavity walls (Q).
    - System impact: determines cavity cooling requirements.
  - Suggested Implementation: At Schafer Livermore.

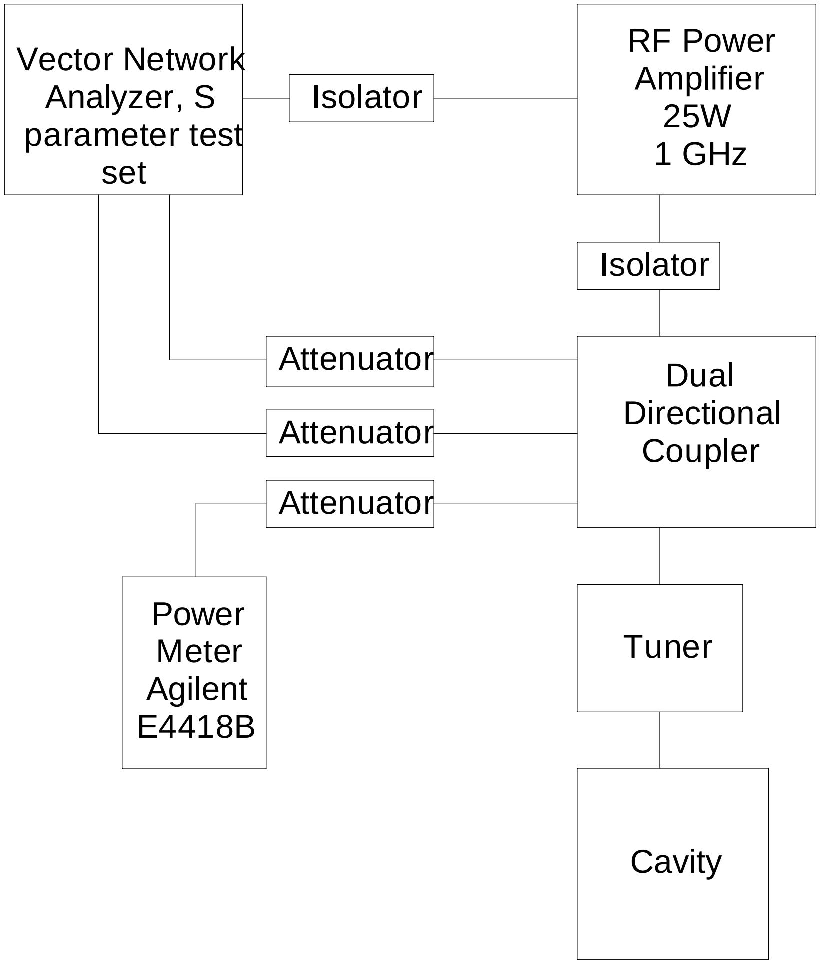
3) Measure the minimum layering time required per target (maximum power sustainable).
  - System impact: determines tritium inventory, scale of target factory.
  - Suggested Implementation: At Vallecitos using DT.

4) Temporal profile of irradiation power.
  - System impact: DT ice may crack if dQ/dt is too large, eliminating ignition; if dQ/dt is too small, excess tritium inventory results.
  - Suggested Implementation: At Vallecitos using DT.

Computations and analysis needed

- Modeling of the RF field for a shell with a thin conducting high Z layer.
  - How uniform is the field inside a real shell with a loss tangent, and with a metal coating? Model using Cfish.
- Analysis of cavity parasitic loss control mechanisms:
  - Is a superconducting coating feasible? (Magnesium diboride seems promising, Tc=40K, Type 1 mechanism, sputter coats).
  - What surface finish specification is required to control arcing? What manufacturing processes could be used to attain the finish?
  - What sort of active tuning method is required to maintain the field uniformity as targets and fixturing progress through the cavity?
- Thermal analysis
  - How much power can we put into a shell?
  - What temperature difference forms across the ice?
    - Preliminary calculation: 250 mK at 10 minute layering time.
    - Will the ice crack as a result of the thermal stress?

RF subsystem


Vector Network Analyzer, S parameter test set

Isolator

RF Power Amplifier 25W 1 GHz

Isolator

Attenuator

Attenuator

Attenuator

Dual Directional Coupler

Power Meter Agilent E4418B

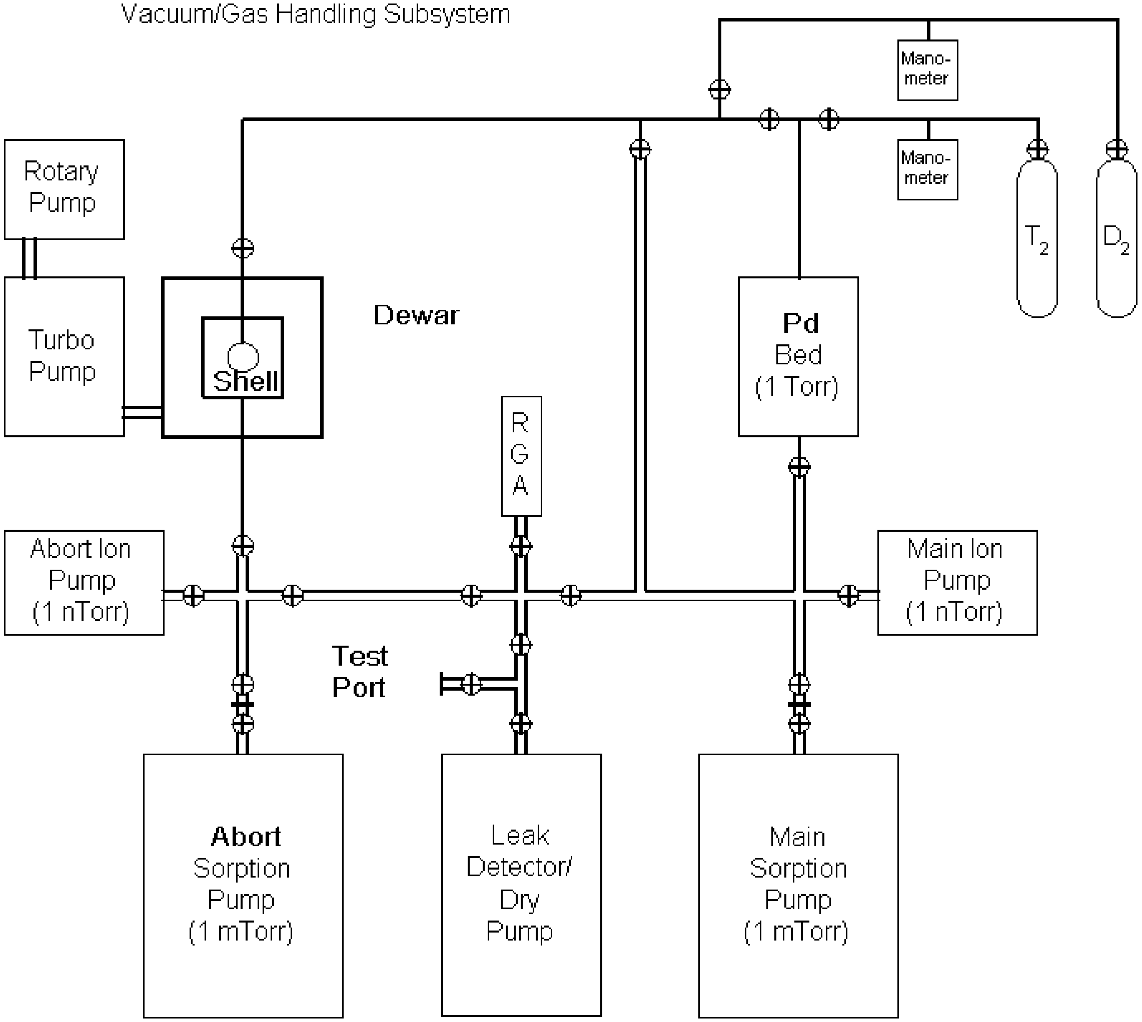
Tuner

Cavity

- Laboratory scale system is shown.
- Network Analyzer:
  - Source
  - Key diagnostic
- Power meter:
  - Accurate power measurements.
- RF Amplifier:
  - 25 Watts
  - 1 GHz
- Dual directional coupler:
  - Both forward and reflected power.
- Tuner to attain critical coupling.
- Full scale IFE layering system would have an identical subsystem with a larger amplifier and more complex tuner.

Vacuum/gas handling subsystem

IFE Rapid Layering Testbed
Vacuum/Gas Handling Subsystem



A laboratory scale system is shown.

Two separate hot systems:

-Abort for capsule failure cleanup.

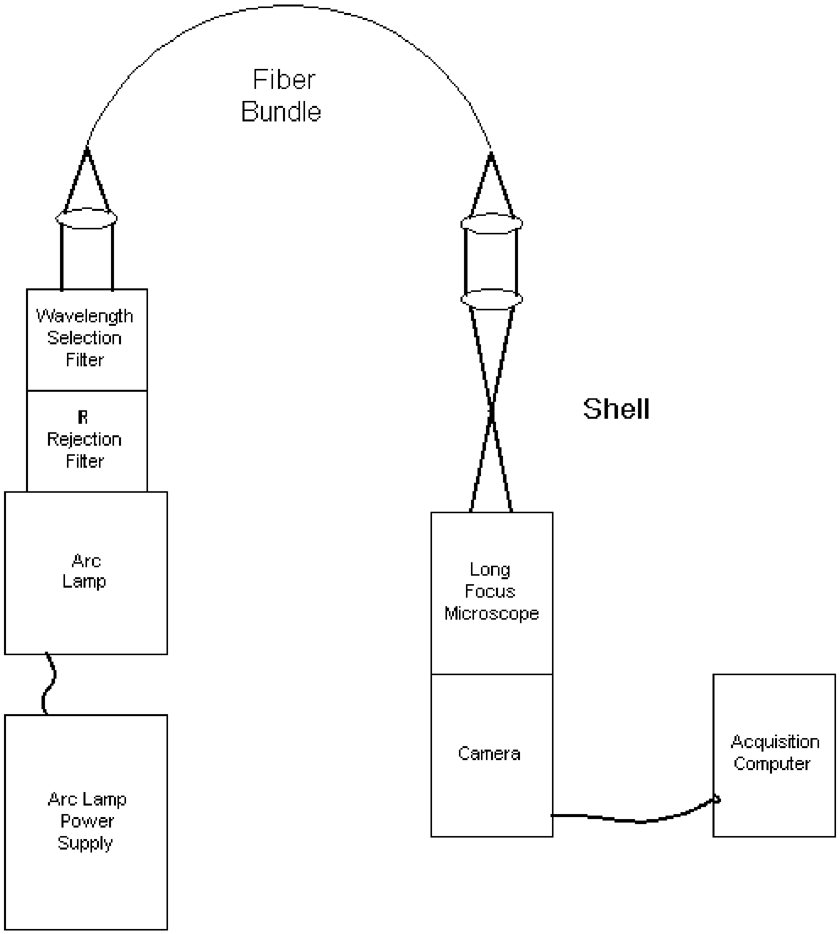
-Main for routine operations.

Tritium stored on the Pd chemisorption bed.

Estimated tritium inventory: 2500 Curies.

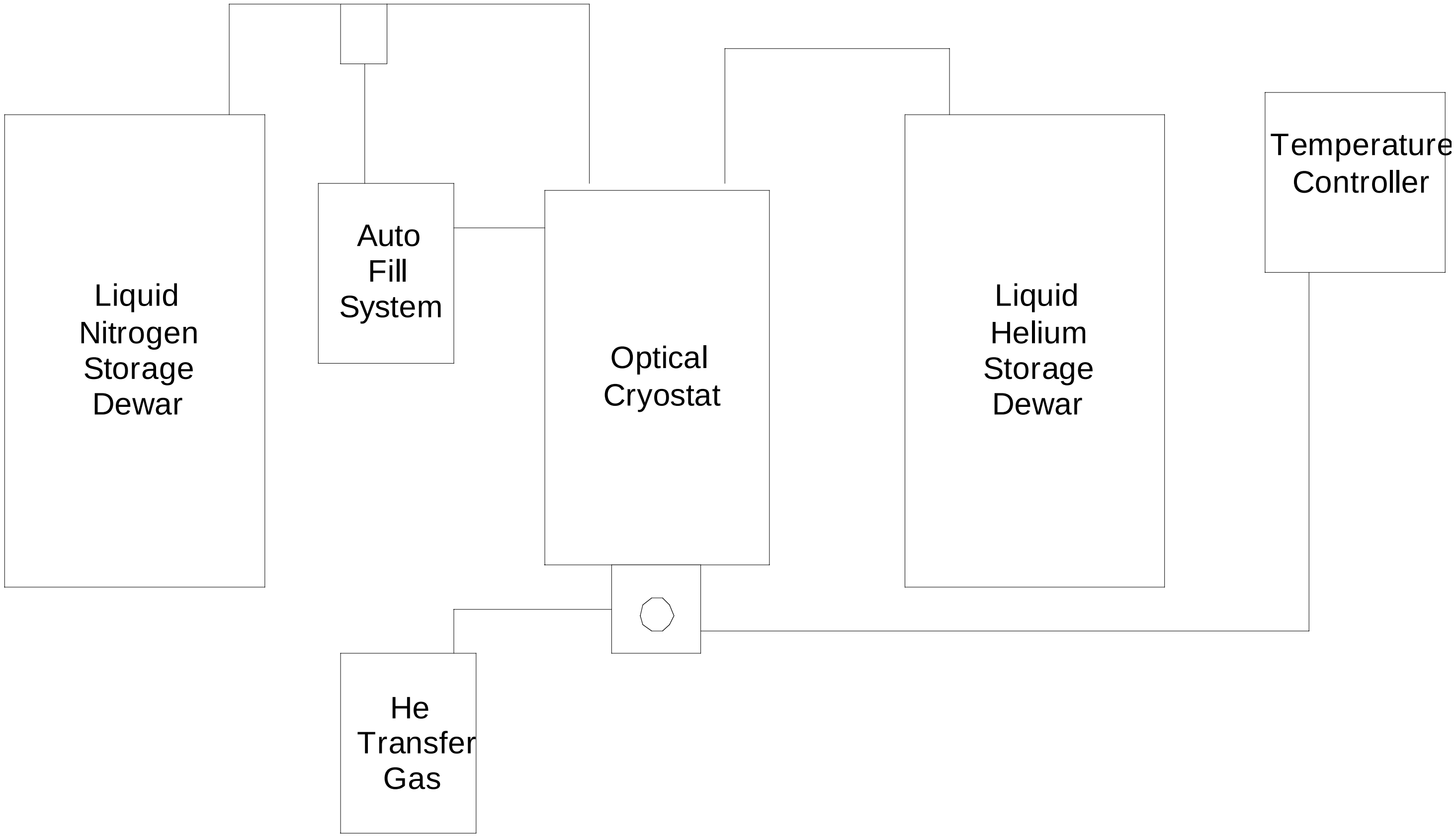
A full scale vacuum/gas filling system might be quite different.

Diagnostic subsystem


IFE Rapid Layering Testbed
Diagnostics Subsystem

- A laboratory scale system is shown.
- Shadowography: baseline diagnostic for ice layer quality.
- UV capable to ease imaging through thin metal coatings.
- Rapid diagnostic suitable for 100% target inspection in an IFE reactor.
  - High speed digital cameras and processors are available.
  - Two axis shadowography is also practical.

Temperature control subsystem



- A laboratory scale system is shown. A full scale IFE reactor might also use He evaporation dewar, but further analysis is needed.

Implementation of the experiments

This scaled sketch indicates the general outline and size of the laboratory equipment.

- Testbed will be constructed outside the tritium facility to minimize cost and schedule.
- Palletized for transfer to the tritium facility.
- Existing GFE at Schafer Livermore can be used to build some of the system.
- Baseline host facility for tritium experiments: GENE, Vallecitos, CA.
- Discussions with the host facility are underway.

Summary and conclusions

- Rapid layering technology can reduce tritium inventories and reduce the size of target factories for IFE reactors.
- Further experimental work and analysis are required to develop a cost effective IFE reactor fuel layering system.
- Proposed experiments and analysis have been detailed.
- A strawman design for an IFE layering experimental apparatus has been developed.
- Discussions with a possible tritium host facility are underway.
- A full scale IFE reactor layering facility strawman design has been presented for discussion purposes.