High Power Hg Target Conceptual Design Review

Hg Target Design

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Outline

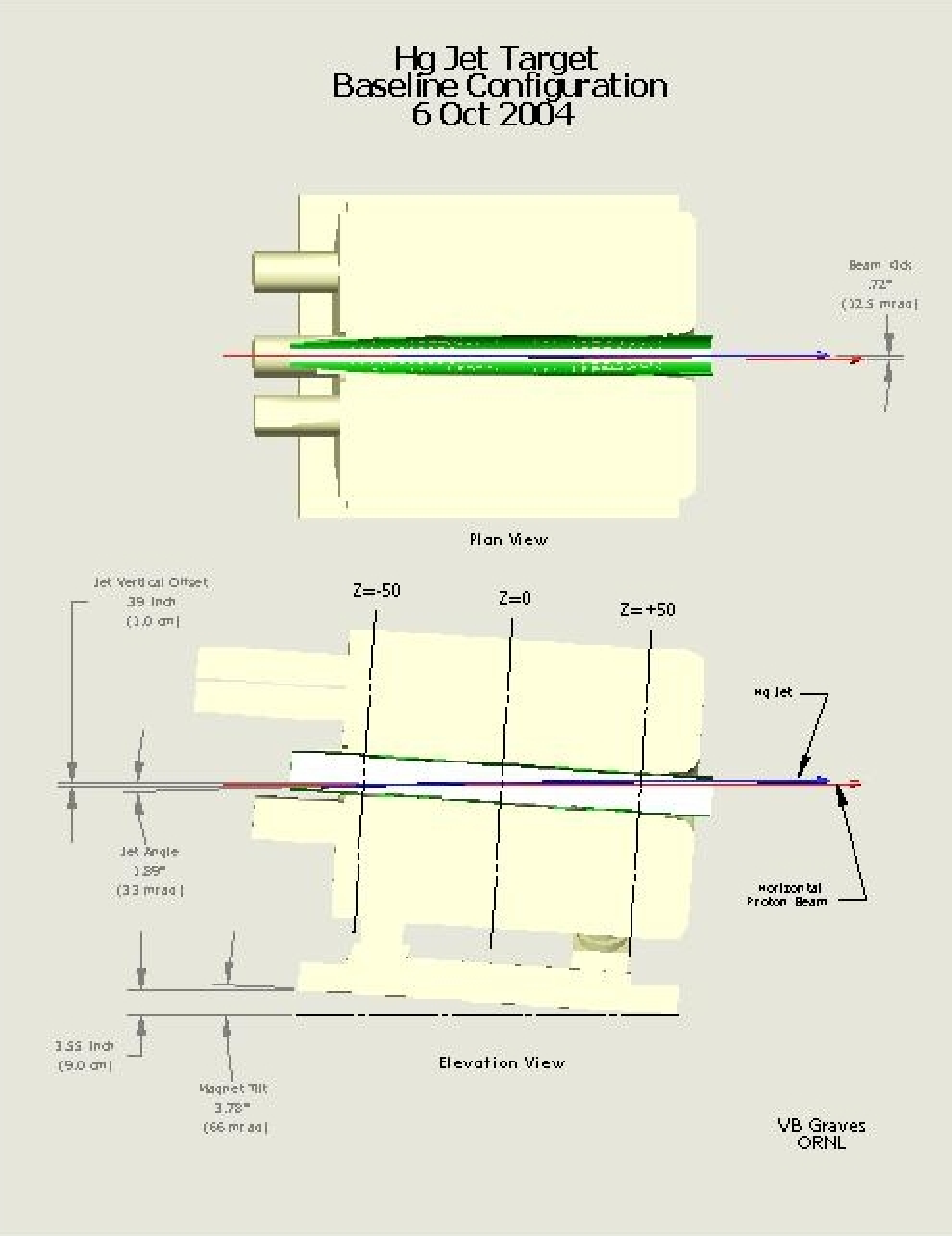
- **Design Constraints**
- **Original Hg delivery concept & issues**
- **Proposed new baseline delivery system**
- **Hg flow analysis in new baseline system**
- **Issues & recommendations**

Design Constraints

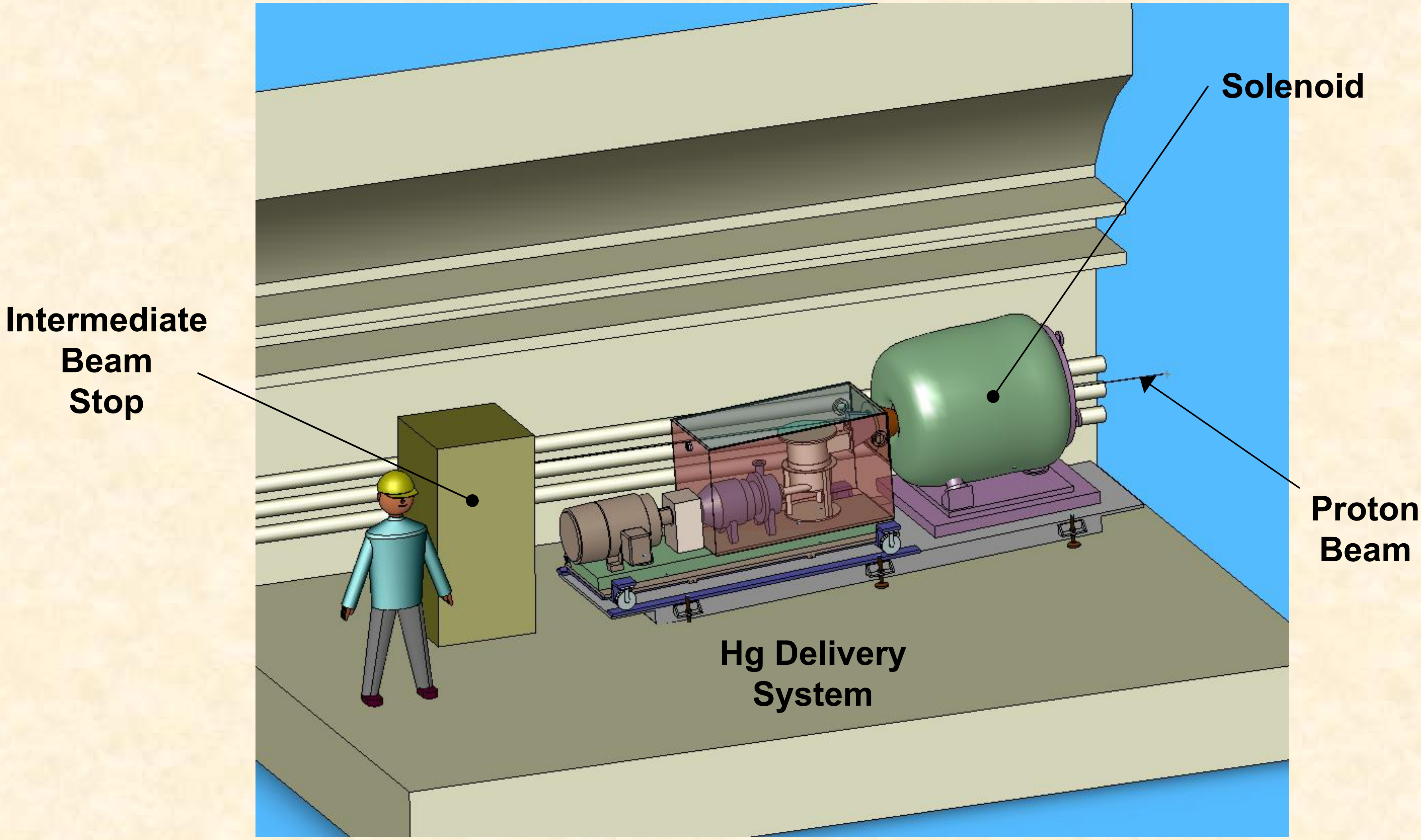
- **Hg Jet**
  - **1cm dia, 20m/s (1.57 liter/s, 24.9 gpm) in same direction as beam**
  - **Free jet created inside 15cm magnet bore**
  - **Smooth, steady-state jet duration overlaps 1-sec max field duration**
- **Integrate optical diagnostics**
- **Materials compatibility with Hg**
- **No target equipment on up-beam end of magnet**
- **Period between beam shots approximately 30 minutes to allow magnet cooling**
- **Component module size limitation is 1.3m x 3m (facility issues)**

Experiment Geometric Configuration

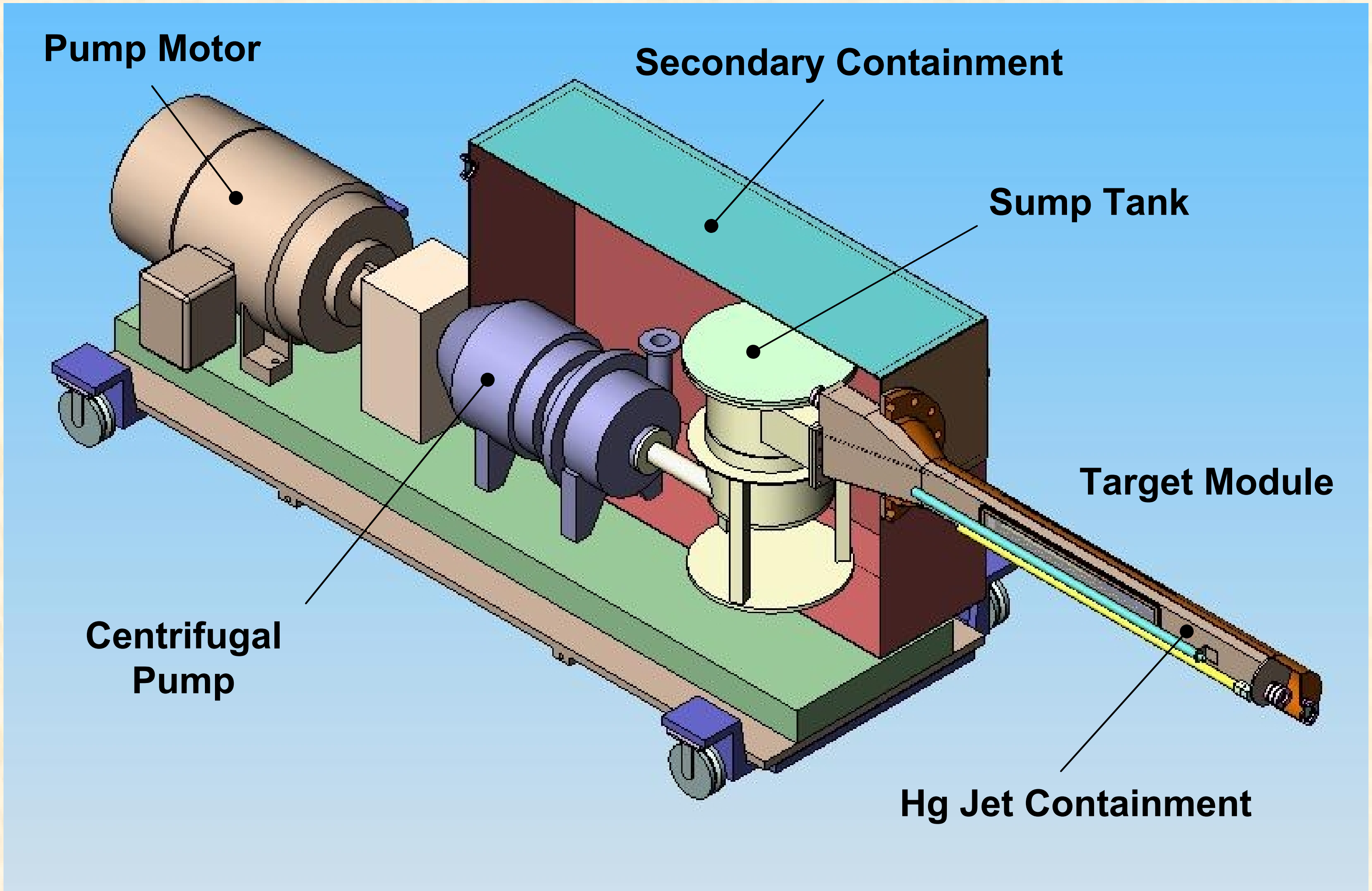
- **Experiment is prototypic of a N.F. facility target layout**
  - **Magnet tilt (wrt beam) = 66 mrad (3.8°)**
  - **Hg jet tilt (wrt magnet axis) = 100 mrad (5.7°)**
  - **Hg jet center intersects beam center at Z=0**



System Overview



Original Hg Delivery System



Pump Issues

- **Pump adds heat to Hg**
  - **Pump delivers nominal 51 bhp at 23% efficiency (60 bhp max)**
  - **Magnetic coupling losses 5.4 hp**
  - **Heat energy into mercury**
    - **LostHP = (bhp - mag)*(1 - eff) + mag = 40.5 hp (30kw)**
    - **With an assumed Vol=12liter, ΔT=2.4°F/sec (1.3°C/sec) due to pump heating only**
- **Max available pump output pressure is 750 psi (50 bar)**
  - **Estimated piping system pressure drop 800-850 psi**

Pump Energy Balance

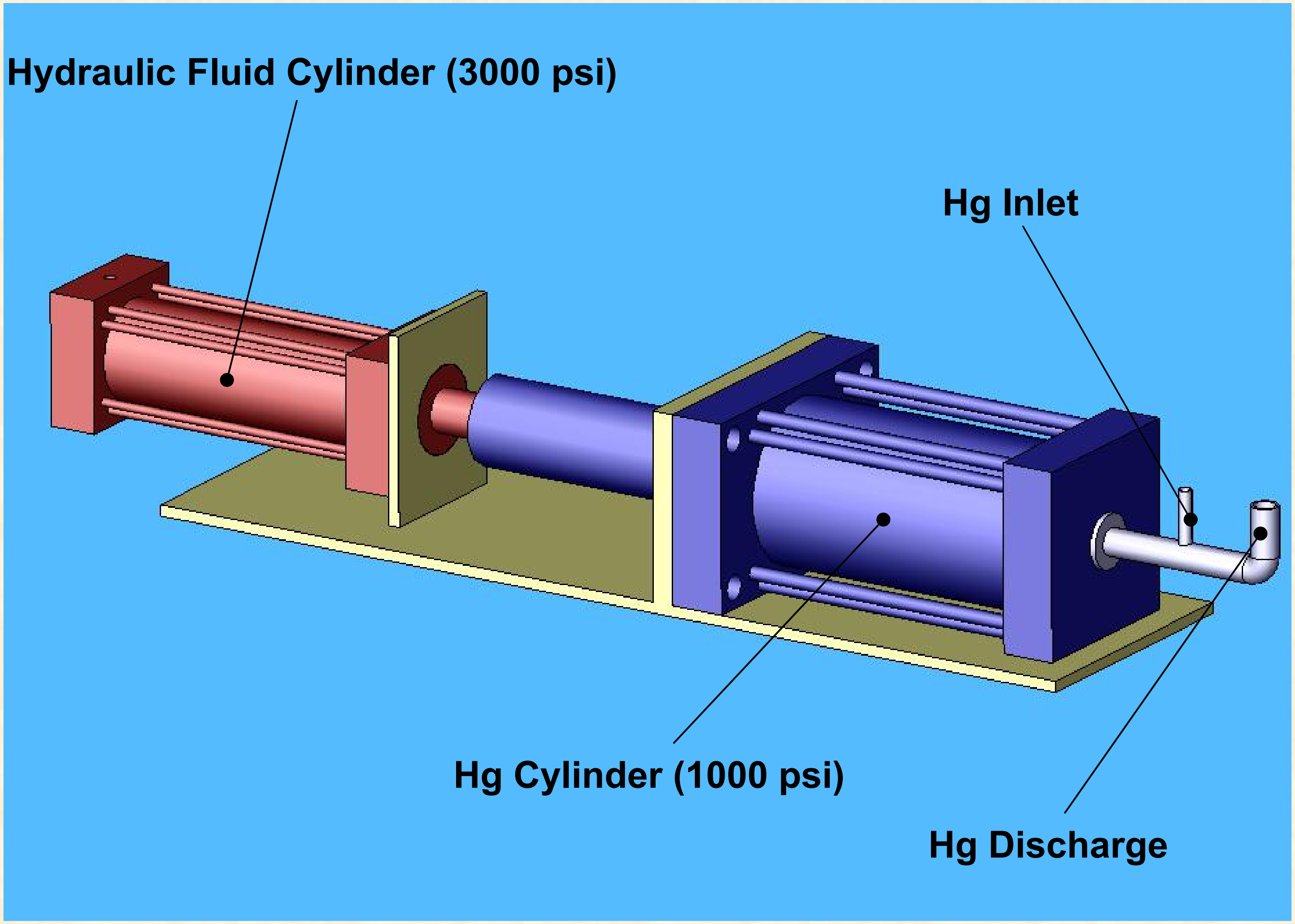
Pump	Input Energy (hp)	Losses	Lost Energy (hp)	Output Energy (hp)	Heat Direct to Tunnel BTU/min	Heat Input to Hg BTU/min	Flow Losses BTU/min	Total Heat Generated BTU/min	KW	HP	Energy to Hg BTU/min	Hg Temp Rise °F/sec
Elect Motor	60	60 hp * 5% inefficiency	3	57	127			127	2	3		
Mag Coupling		5.4hp actual coupling loss per vendor data	5.4	51.6	229			229	4	5		
Hg Pump		40.5hp actual pump loss per vendor data	40.5	11.1		1719		1719	30	40	1719	
Hg Flow		800psi*25gpm	12	-1			526	526	9	12	526	
				Totals	356	1719	526	2601	46	61	2245	3.1

Possible Solutions

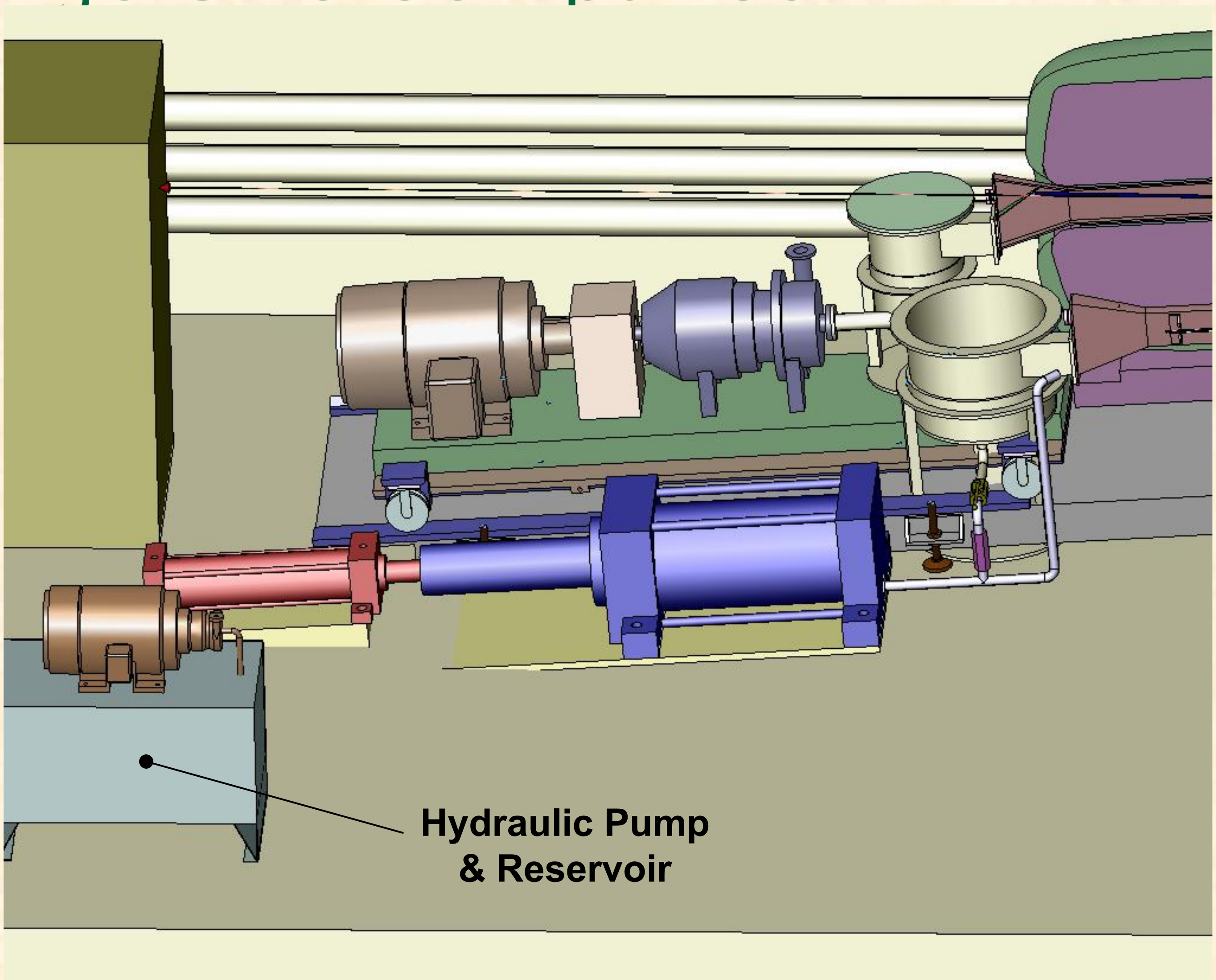
- **Heat issue**
  - **Increase Hg volume (ΔT decreases linearly with Hg mass)**
  - **Add heat exchanger for system testing**
    - **May not be needed during CERN tests**
- **Pump discharge pressure issue**
  - **Vendor specified pump to provide max DP**
  - **Investigate alternative Hg delivery systems**

Nature of experiment lends itself to non-continuous flow approach, so…

Alternative Hg Delivery System



Syringe Size Comparison



System Energy Comparison

Pump					Heat Direct to Tunnel	Heat Input to Hg	Flow Losses	Total Heat Generated			Energy to Hg	Hg Temp Rise
	Input Energy (hp)	Losses	Lost Energy (hp)	Output Energy (hp)	BTU/min	BTU/min	BTU/min	BTU/min	KW	HP	BTU/min	°F/sec
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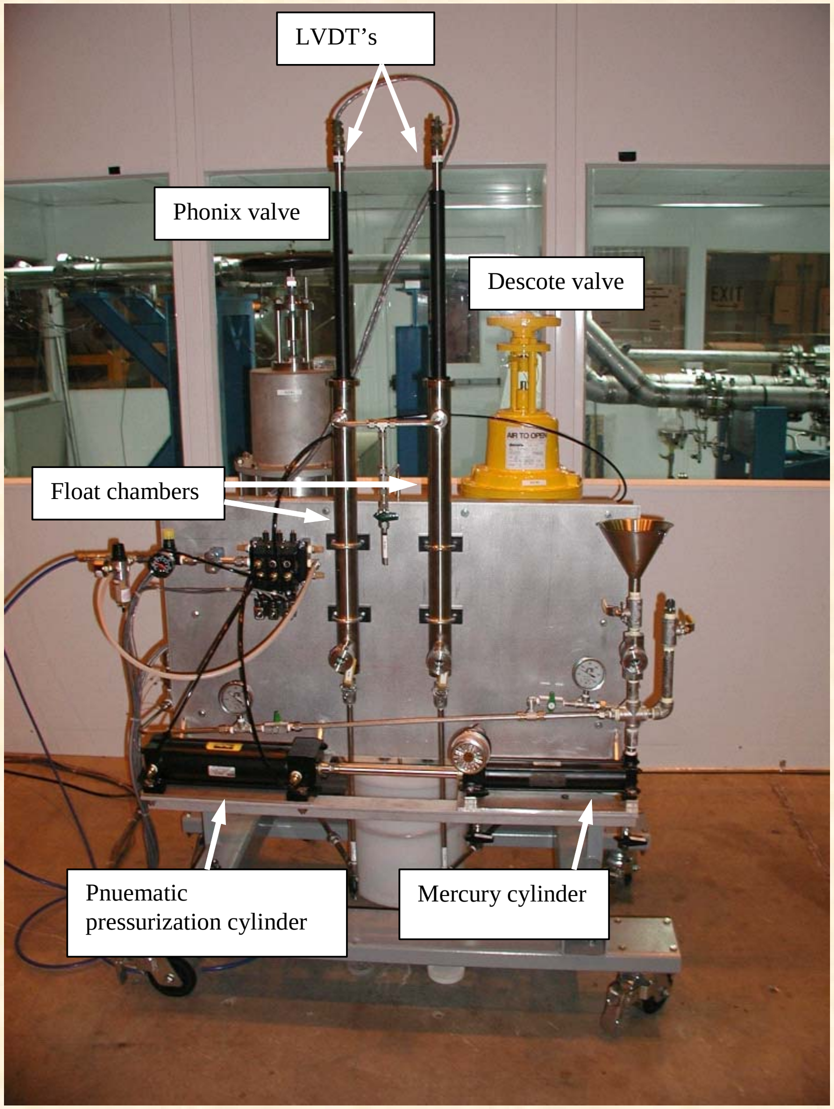
				Totals	356	1719	526	2601	46	61	2245	3.1
Syringe												
Elect Motor	20	20 hp * 5% inefficiency	1	19	42			42	1	1		
Hyd Pump		energy performed on piston = press*area*dist/time	11									
Hyd Pump		pump inefficiency	8	11	340			340	6	8		
Piston Energy to Hg		no losses		11								
Hg Flow		800psi*25gpm	12	-1			526	526	9	12	526	
				Totals	382		526	908	16	21	526	0.7

Syringe Performance Benefits

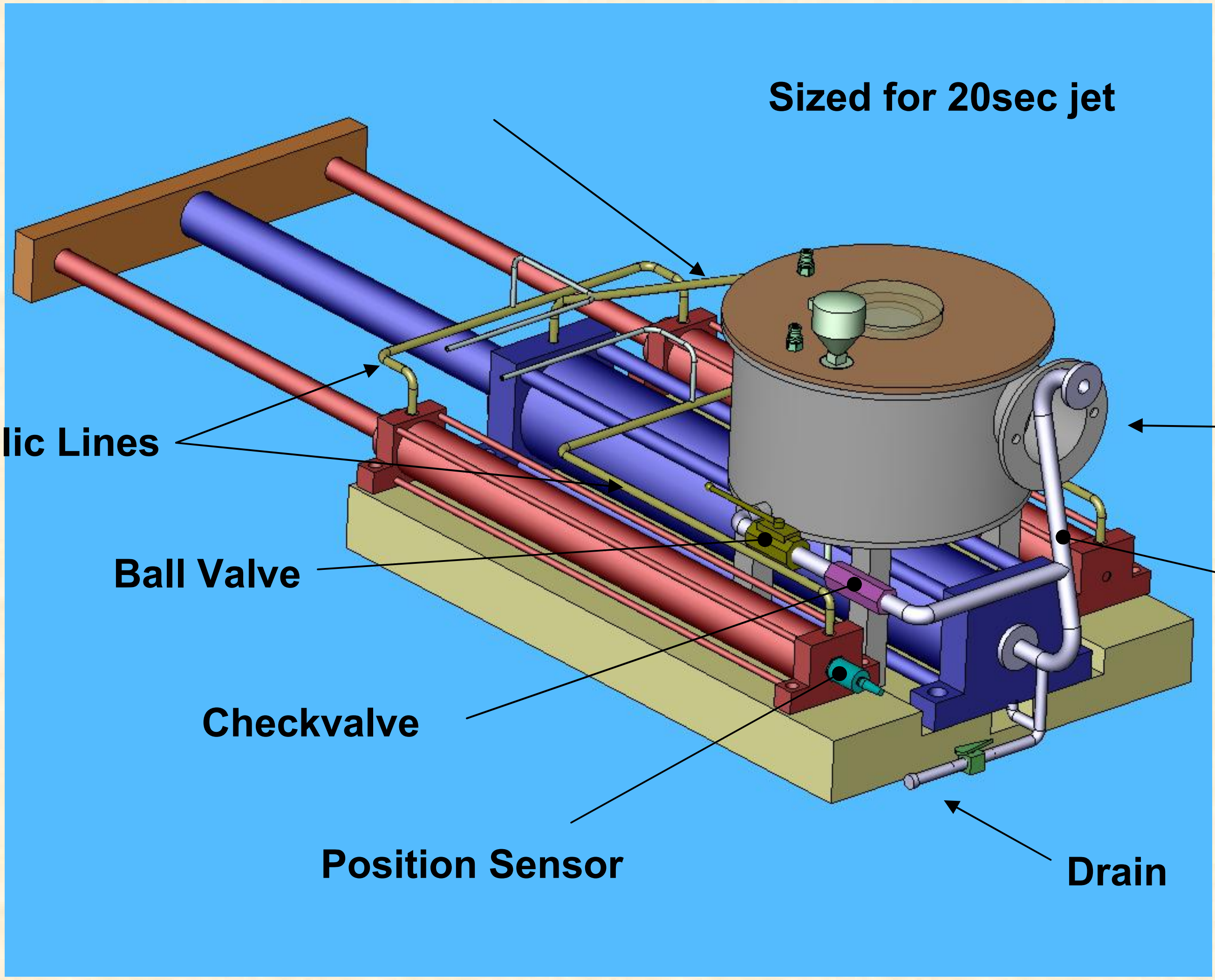
- **Piston-driven jet has excess capacity to overcome flow losses**
- **No significant heat imparted to Hg by piston**
  - **Heat losses isolated to hydraulic system**
  - **Flow losses identical to those in pump system**
  - **No heat exchanger required**
- **Syringe design may be smaller than shown, depending on Hg volume required**
  - **1.6 liter/s → 48 liter for 30sec, 24 liter for 15sec**
  - **Concept shown in size comparison was sized for 30sec jet**
- **Lower power requirements**
  - **20hp hydraulic pump motor vs. 60hp centrifugal pump motor**

Hg Cylinder Experience

- **SNS test stand used pneumatic cylinders to cycle candidate drain valves several thousand cycles with no leaks**
- **Low-pressure application with automated controls**

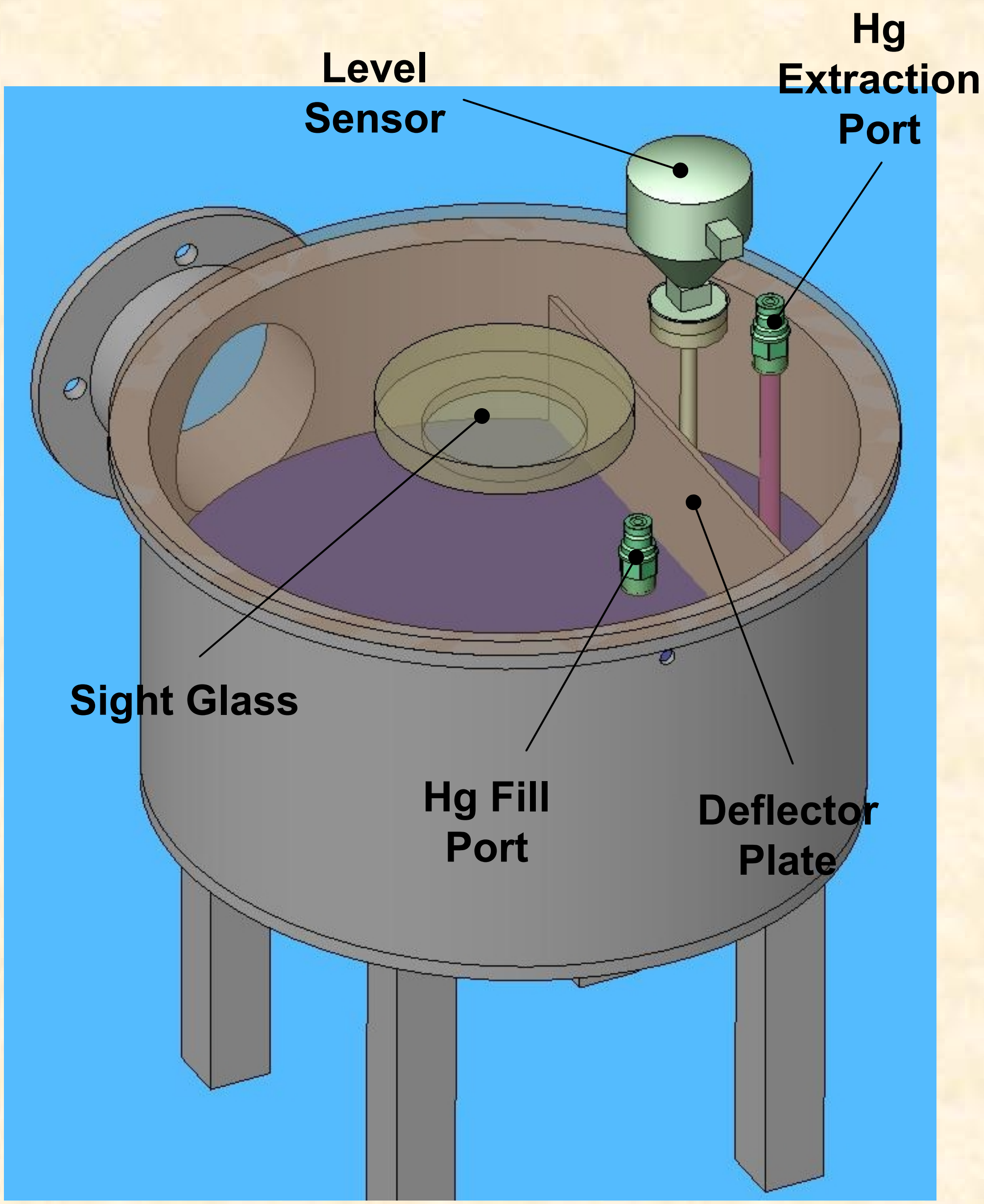


New Baseline Target System



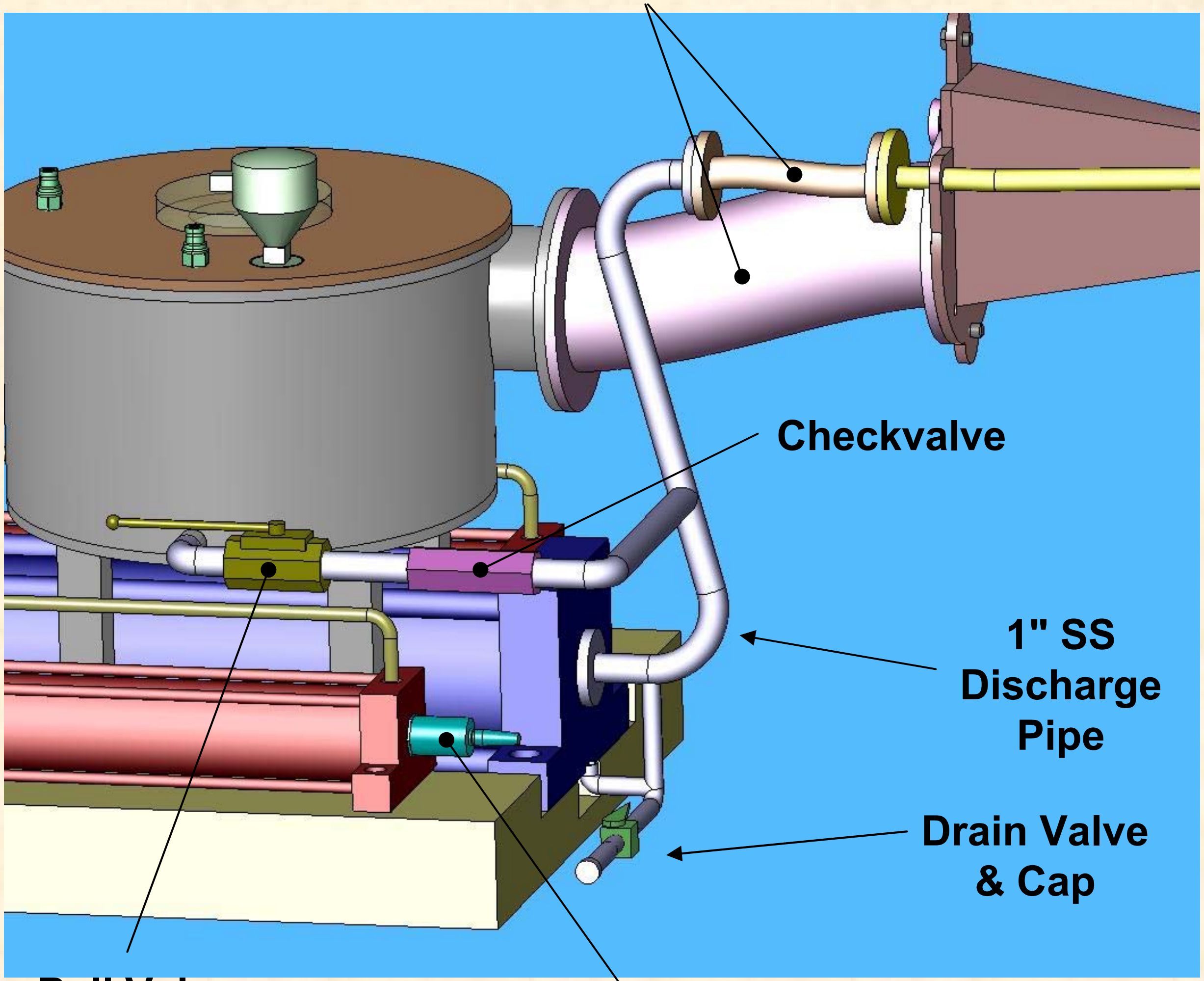
Sump Tank

- **22" SS pipe**
- **Hg inventory**
  - **36 liter, 1068 lb**
  - **6 inch depth**
- **Incorporates float-type level sensor, Hg fill & extraction ports**
- **Thermocouple on sump exterior or in direct Hg contact**
- **Potential use as storage tank for shipping**

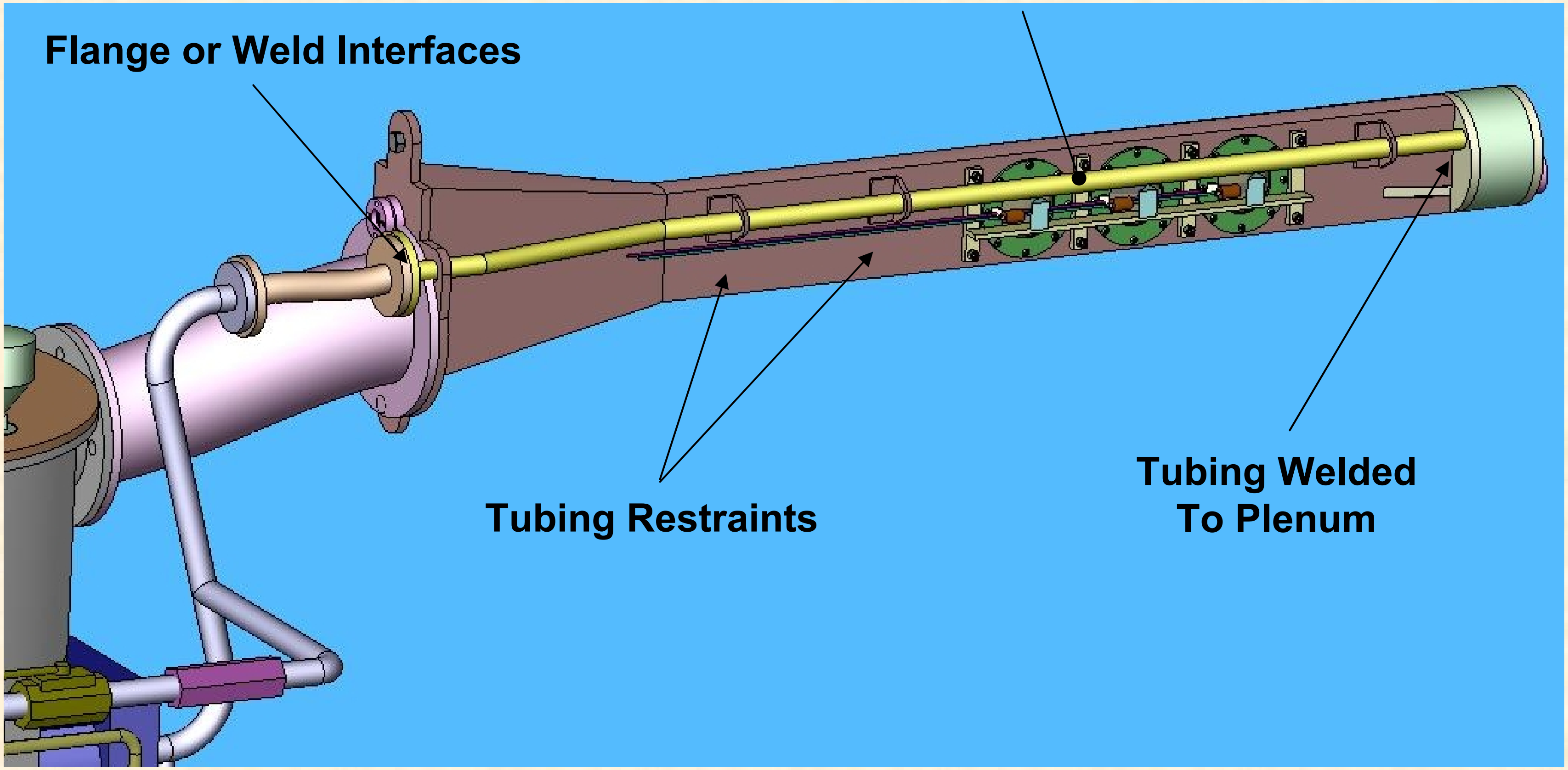


Syringe

- **8" Hg cylinder, 4" hydraulic cylinders, 39" strokes**
  - **Sizes chosen based on costs**
- **Position sensor allows actual flowrate calculations**
- **Checkvalve prevents backflow into sump**
  - **Must remain submerged throughout experiment to prevent air intake in cylinder**
- **Discharge pipe will require structural supports**

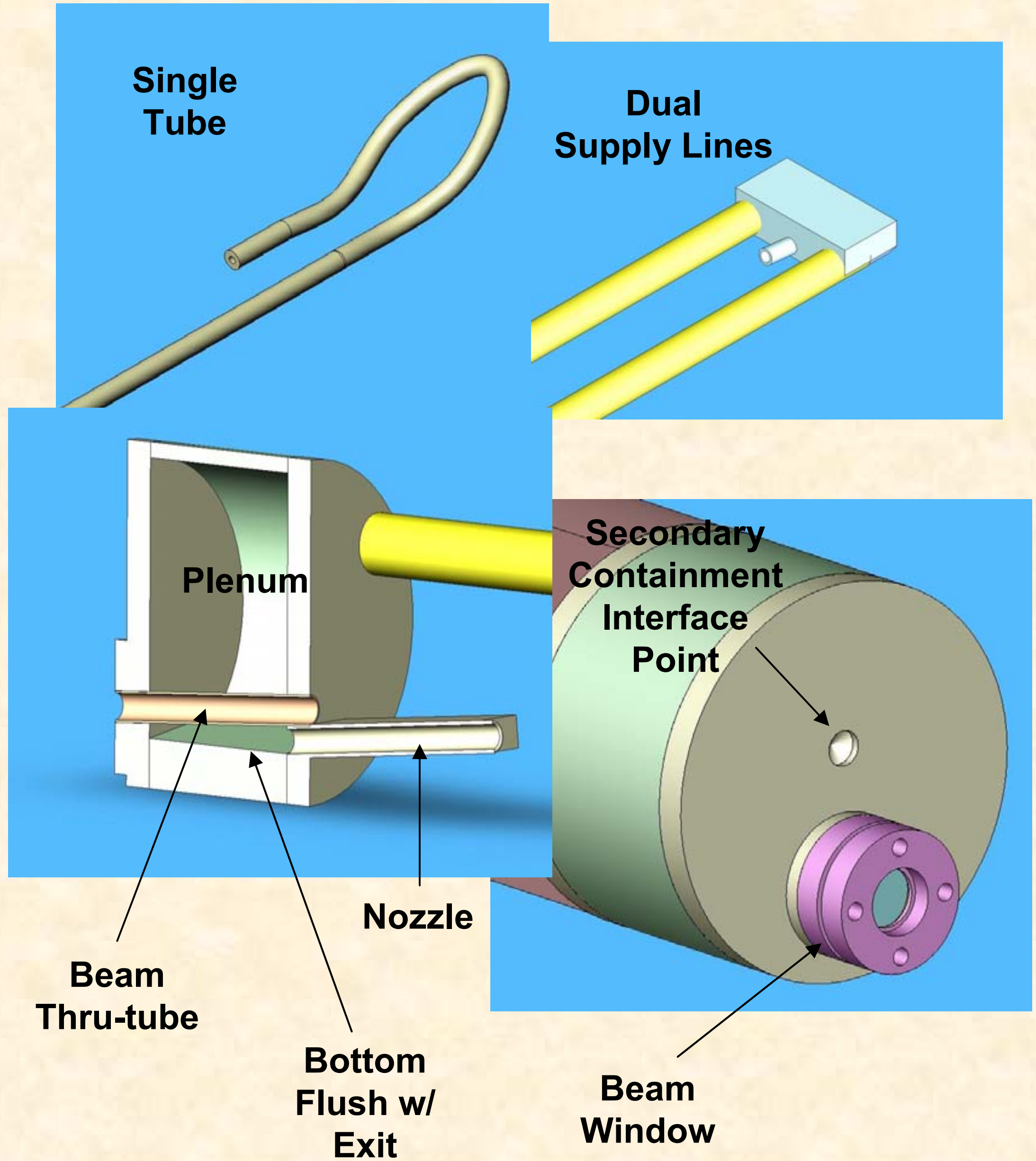


Hg Supply Tubing



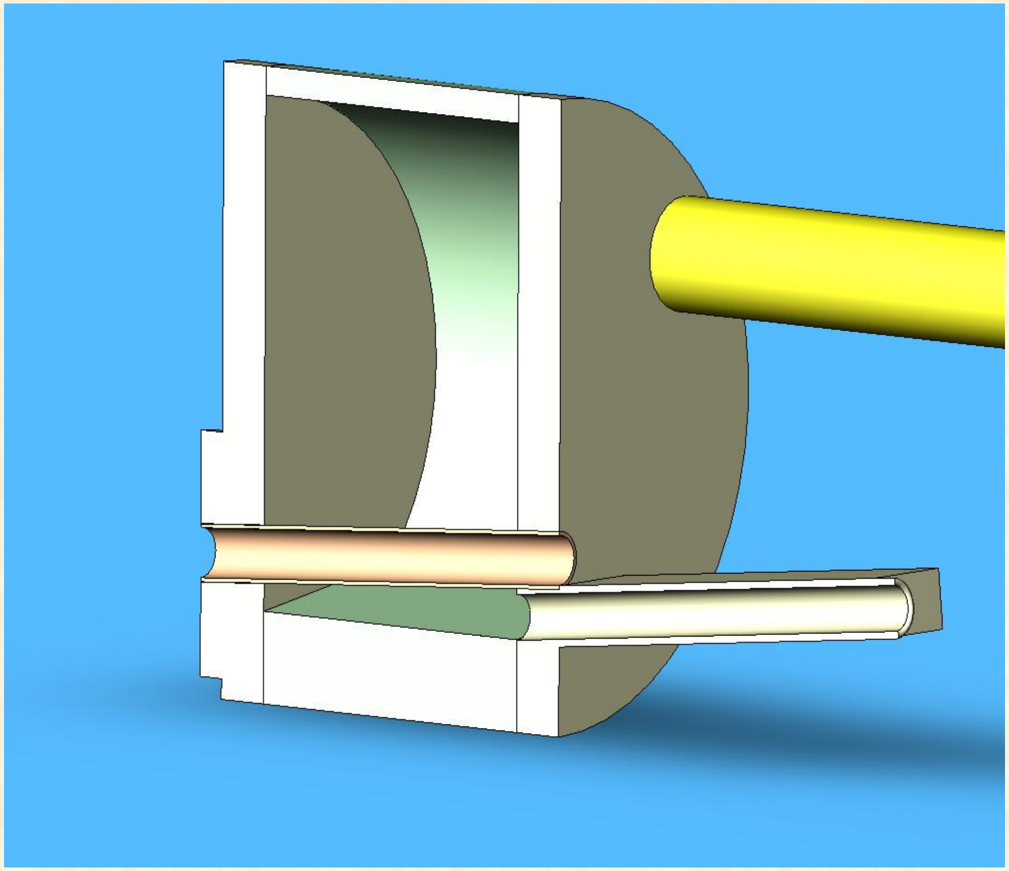
Hg Plenum

- **Purpose is to provide reservoir to allow Hg to change direction in confined space**
- **Open chamber with nozzle exit and beam thru-tube**
- **Raised bottom for drainage**



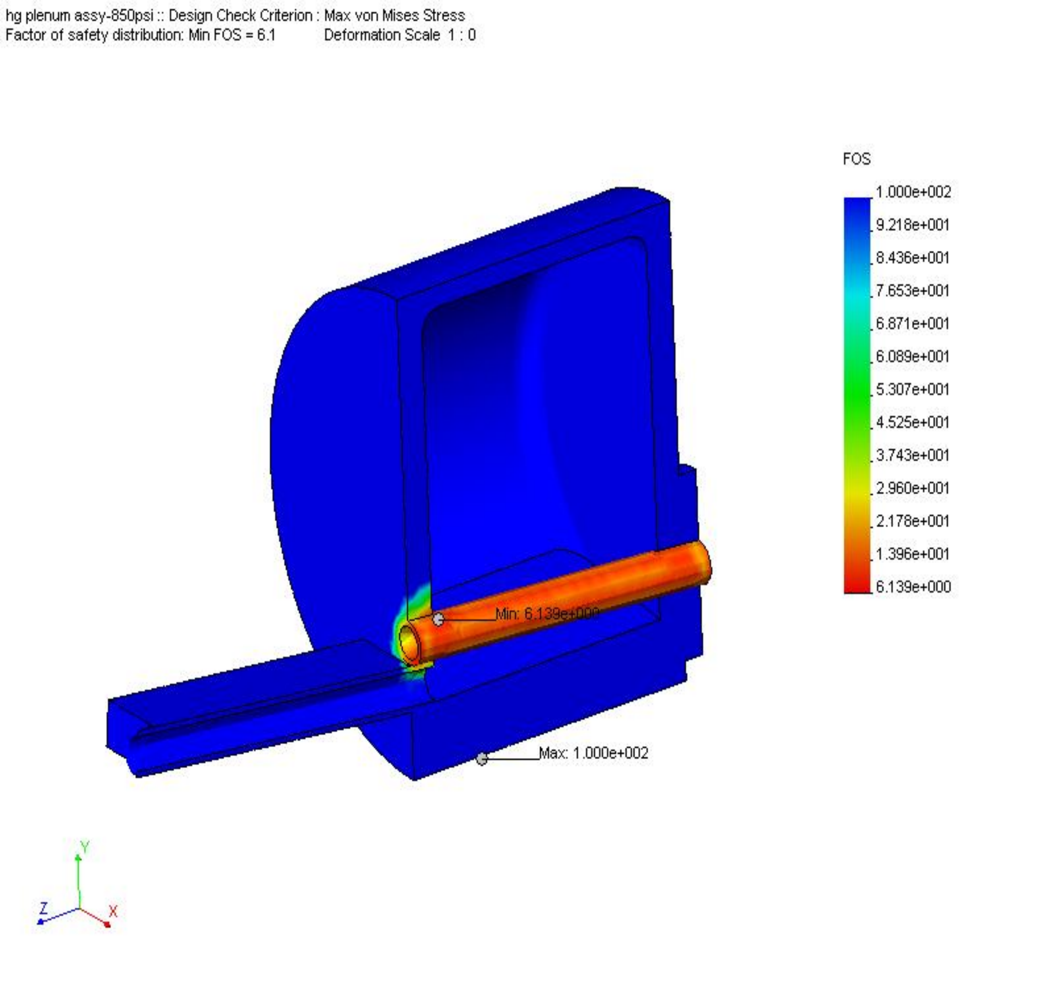
Plenum Issue

- **Trapped air in plenum**
  - **Swept out with Hg**
  - **Compressed and acts like spring**
- **Solutions**
  - **Evacuate system prior to operation**
    - **Hg vapor issue**
  - **Provide means to quickly move air out nozzle**



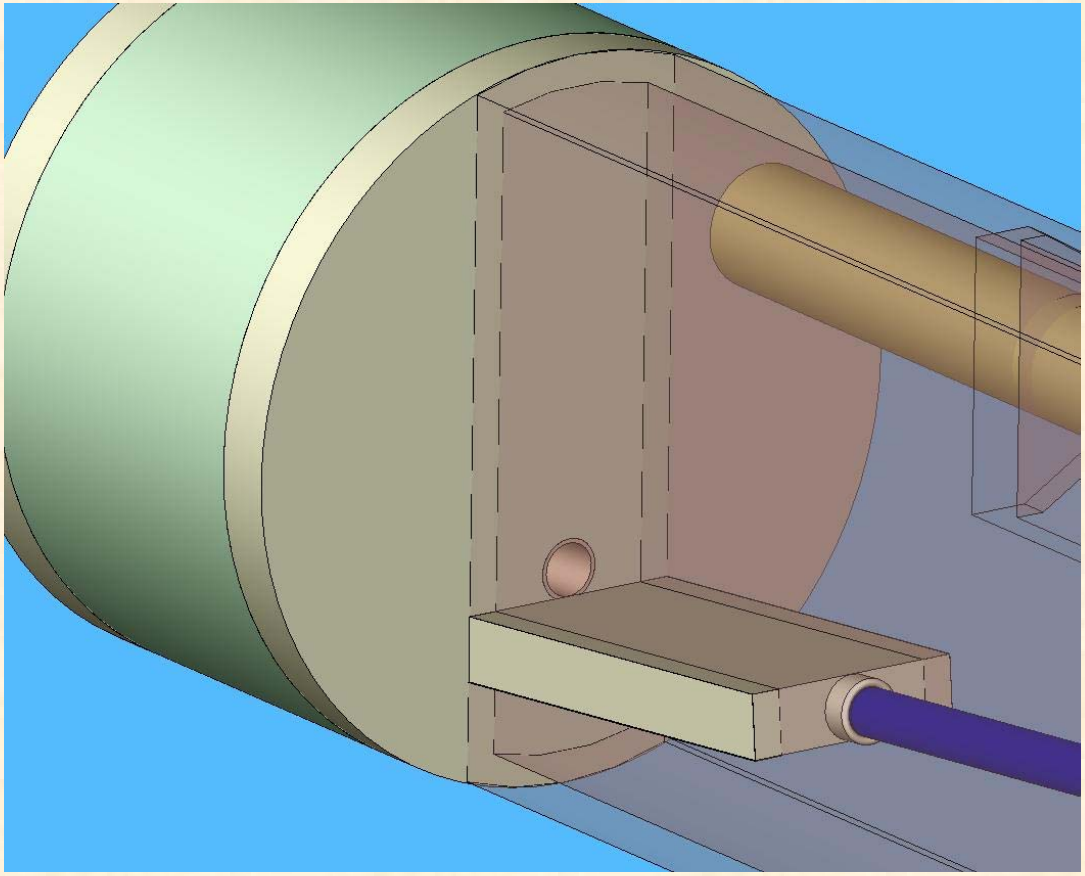
Plenum Structural Design

- **Static FEA performed using pressure load of 850psi on interior surfaces**
- **Minimum FOS = 6 around beam thru-tube**
- **Flow analysis presented by M. Wendel**

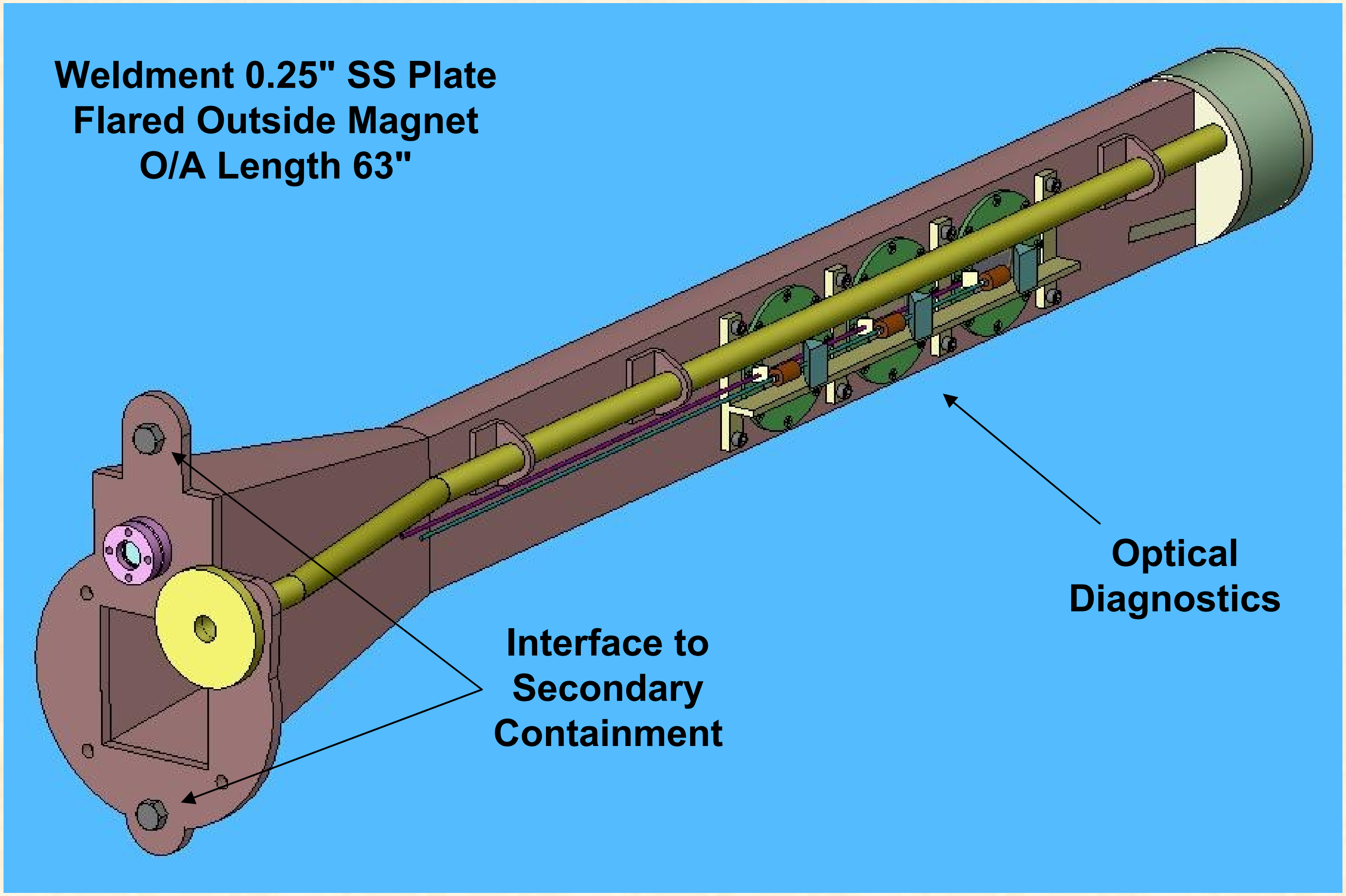


Plenum/Nozzle Integration

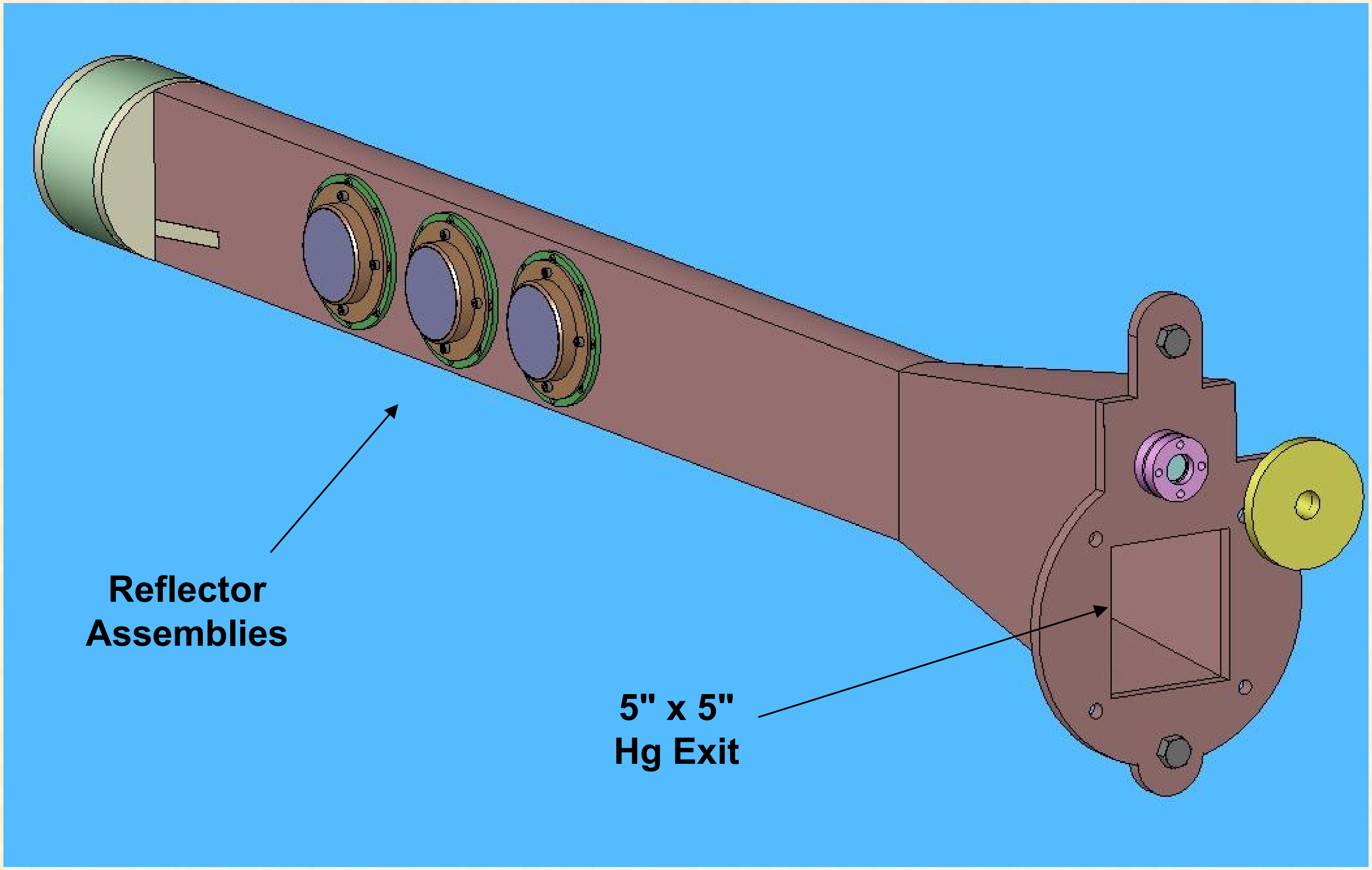
- **Plenum & nozzle welded to primary containment – no nozzle replacement**
- **Nozzle side restraints resist field-induced motion in Hg**
- **Length set at 10X dia = 4"**
- **Changes to inlet/exit required based on flow analysis**



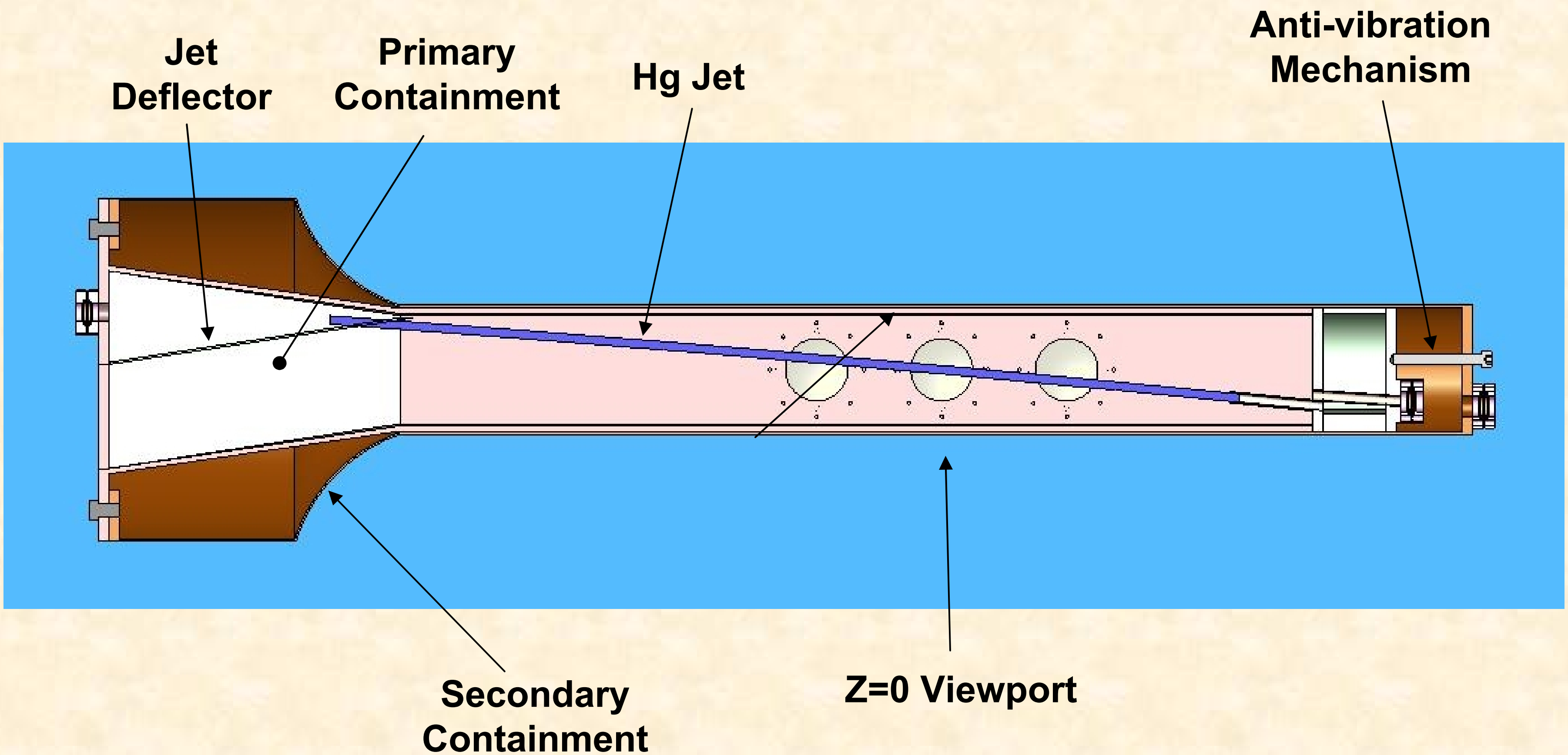
Primary Containment – Right Side



Primary Containment – Left Side



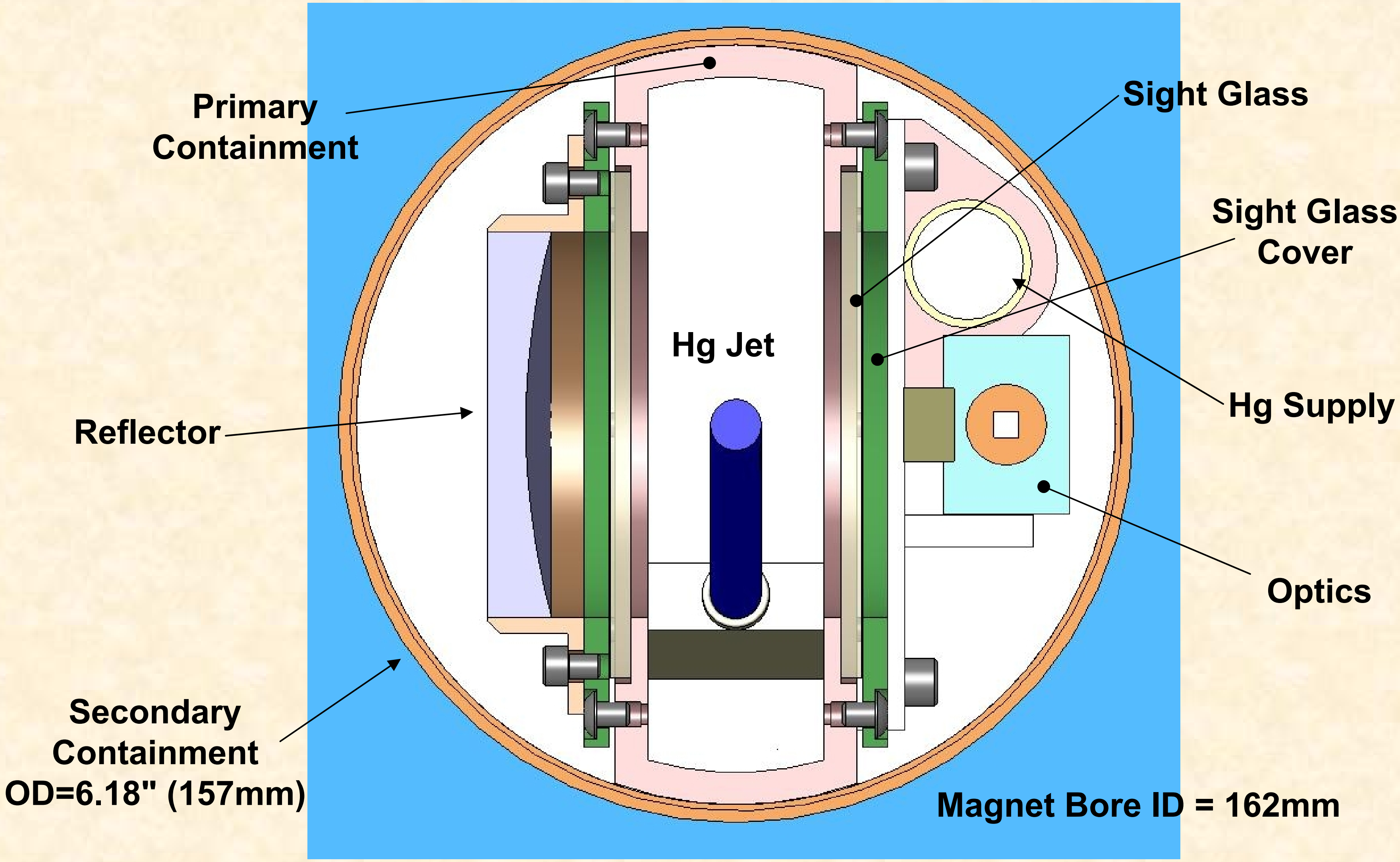
Primary Containment – Side View



Deflector

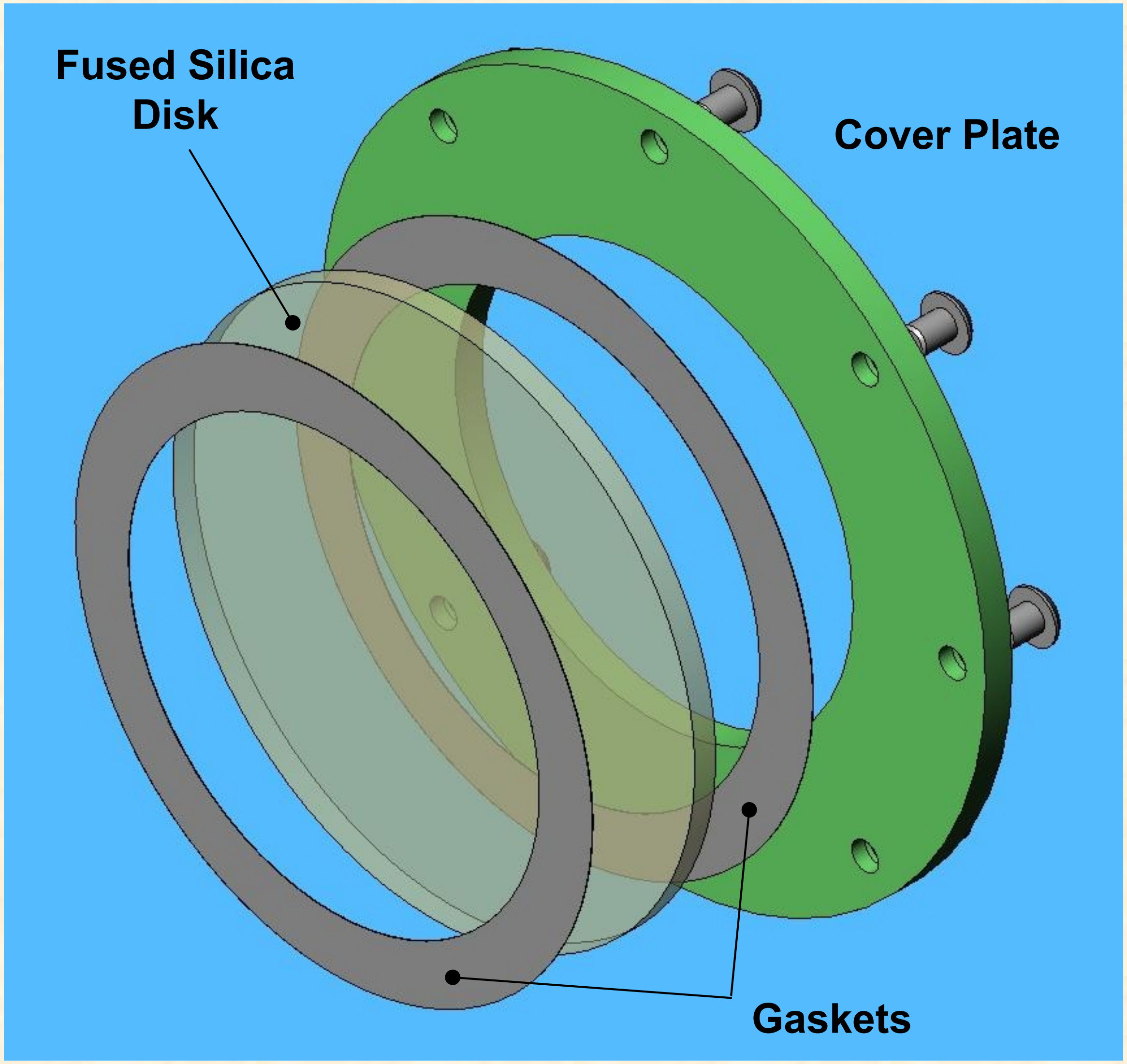
- **Purpose is to enhance Hg drainage into sump tank by minimizing splashing and Hg drops back into magnet bore**
- **Material is Ti6Al4V, same material used for beam windows**
- **Designed as flat plate with low angle of incidence**
  - **Some curvature may be needed to aid in flow control**
  - **Princeton tests can be used to provide design feedback**
- **Stress calculation indicates Hg jet impact force <100lb**
  - **Deflector thickness of 0.1" provides FOS=5.5**

Primary Containment Cross Section



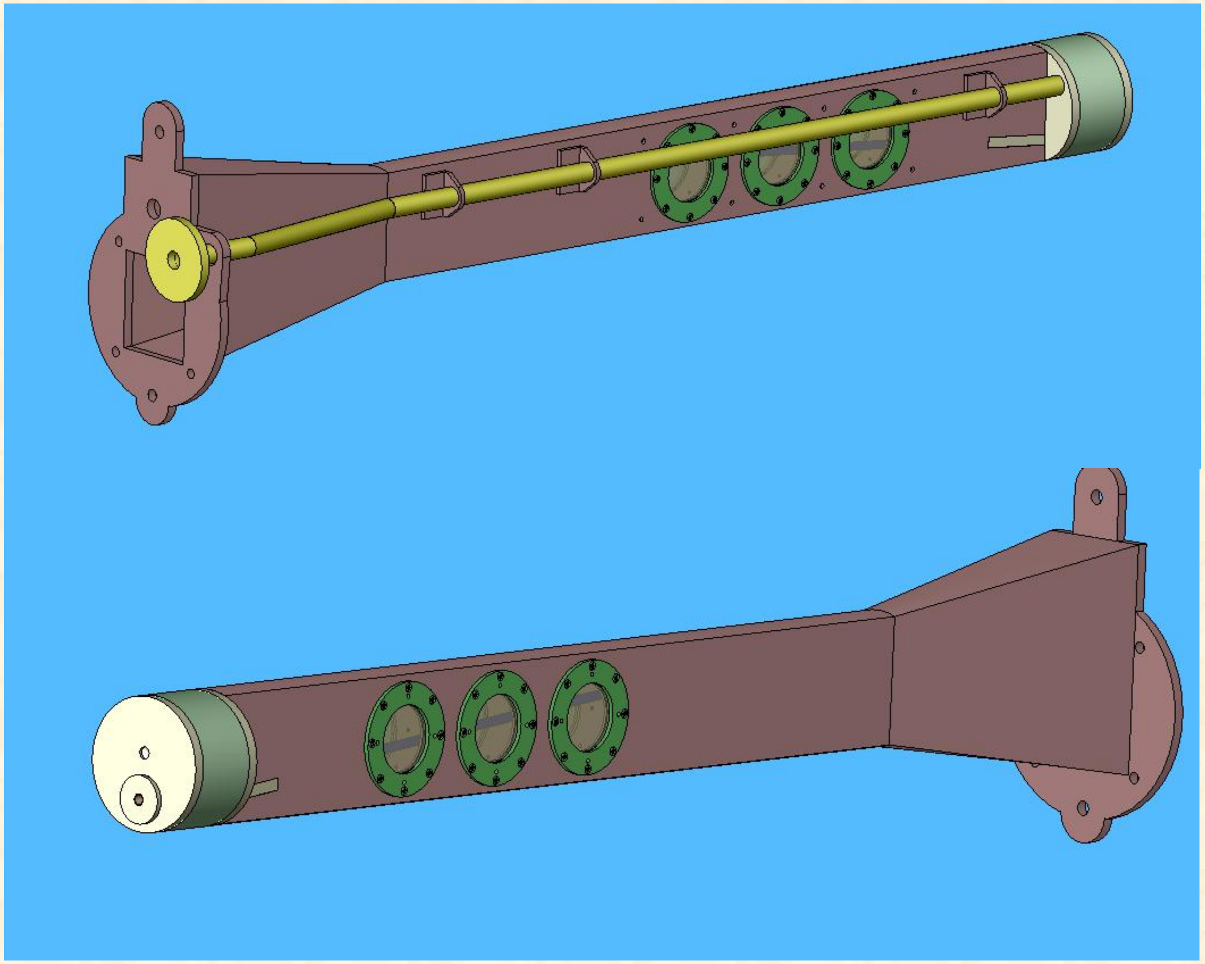
Viewports

- **Optical viewport laminated with rad-resistant gaskets**
- **Mechanically fastened cover plate**
- **Structural rigidity of disk needs further analysis**



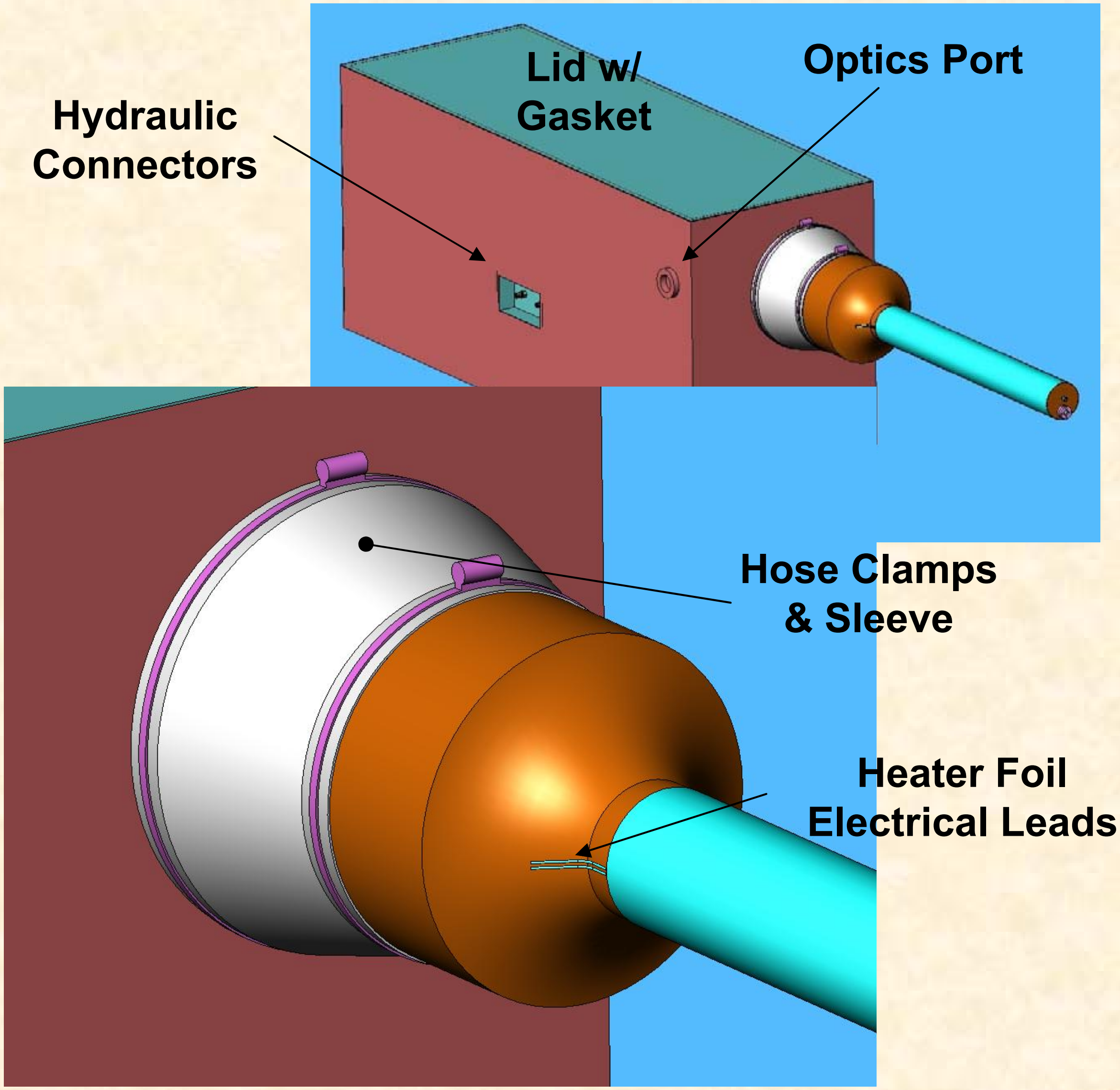
Primary Containment As Supplied

- **Viewport components fabricated as part of primary containment**
- **Windows & optical diagnostics to be provided by others**
- **Interface sketches will be provided in Final Design**



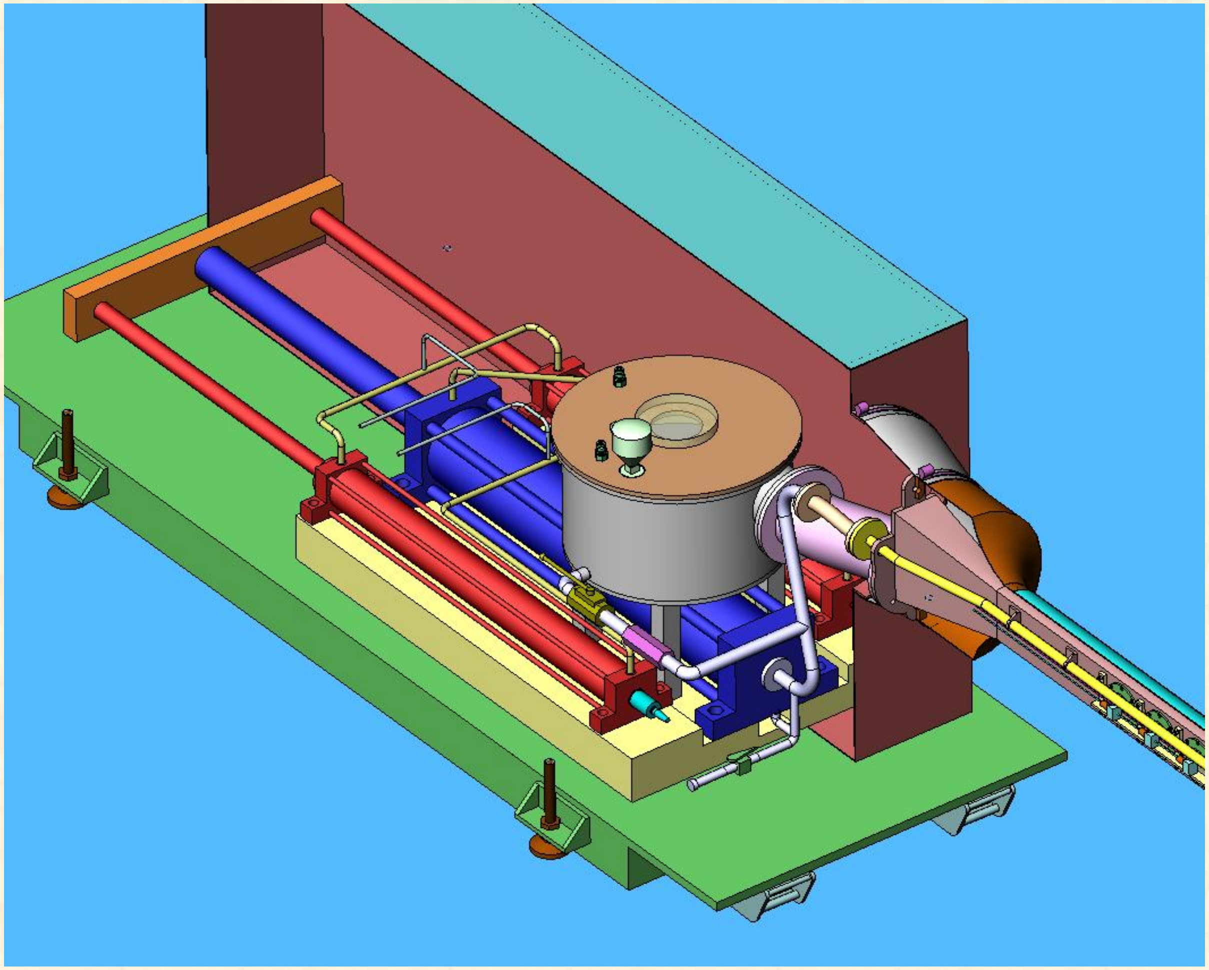
Secondary Containment

- **SS sheet metal enclosure around entire primary system**
- **Contains Hg leaks, provides access to monitor Hg vapors**
- **Provides access to optical diagnostics, hydraulics, and sensors**
- **Incorporates beam windows**
- **3 components: hydraulics box, target cover, connecting rubber sleeve**



Hg Target System

- **Secondary tank dimensions 102x36x45" (2.6x0.9x1.1m) without support base**
- **Need to reduce footprint**
  - **Facility limits are 3m x 1.3m**

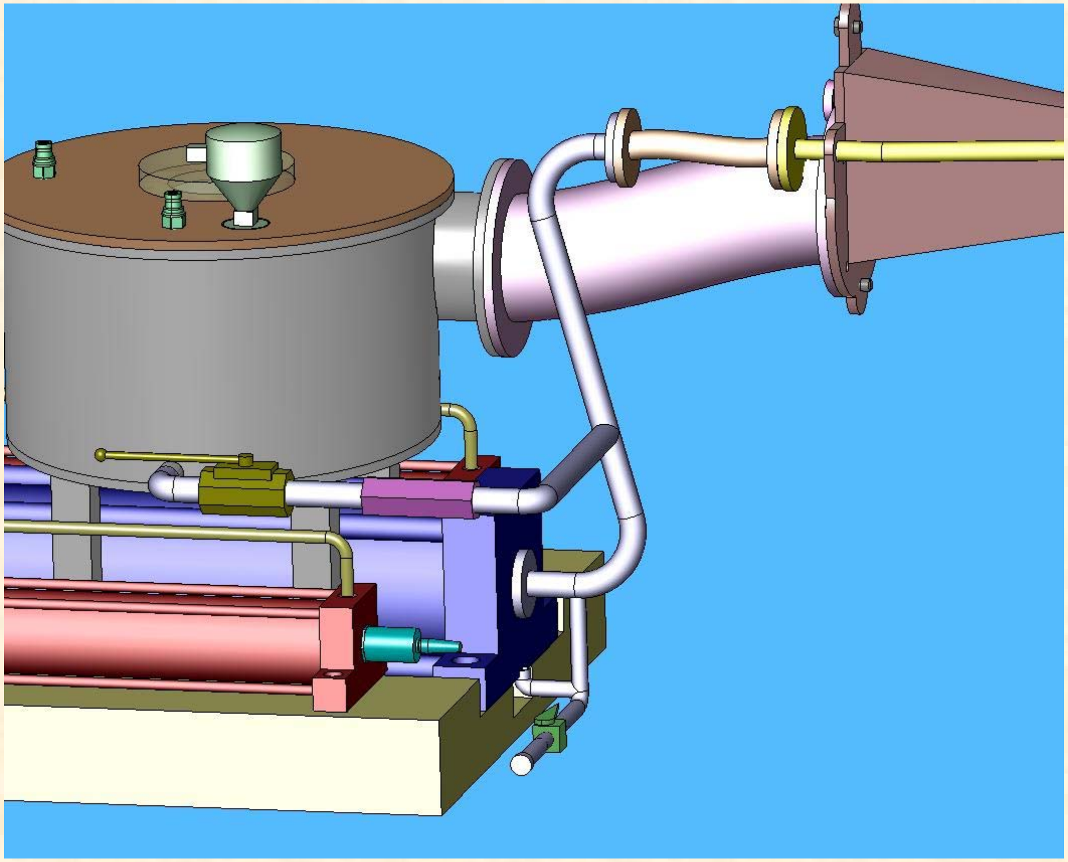


Mechanical Design Issues

- **Nozzle design**
  - More analysis needed
  - Nozzle/deflector designs need validation
  - Air entrapment in plenum
  - Removable nozzle
- **Viewports**
  - Structural rigidity of viewport optics
  - May require testing
- **System sizing**
  - Footprint for 20sec syringe too large
    - Minor width reduction possible
    - Need to decrease required stroke
  - For 8" cylinder, 1 sec jet duration requires 1.9" stroke
    - Reducing jet duration by 1 sec reduces overall cylinder length by 3.8"
  - Recommend reducing max jet duration to 15s

Hg Flow Analysis

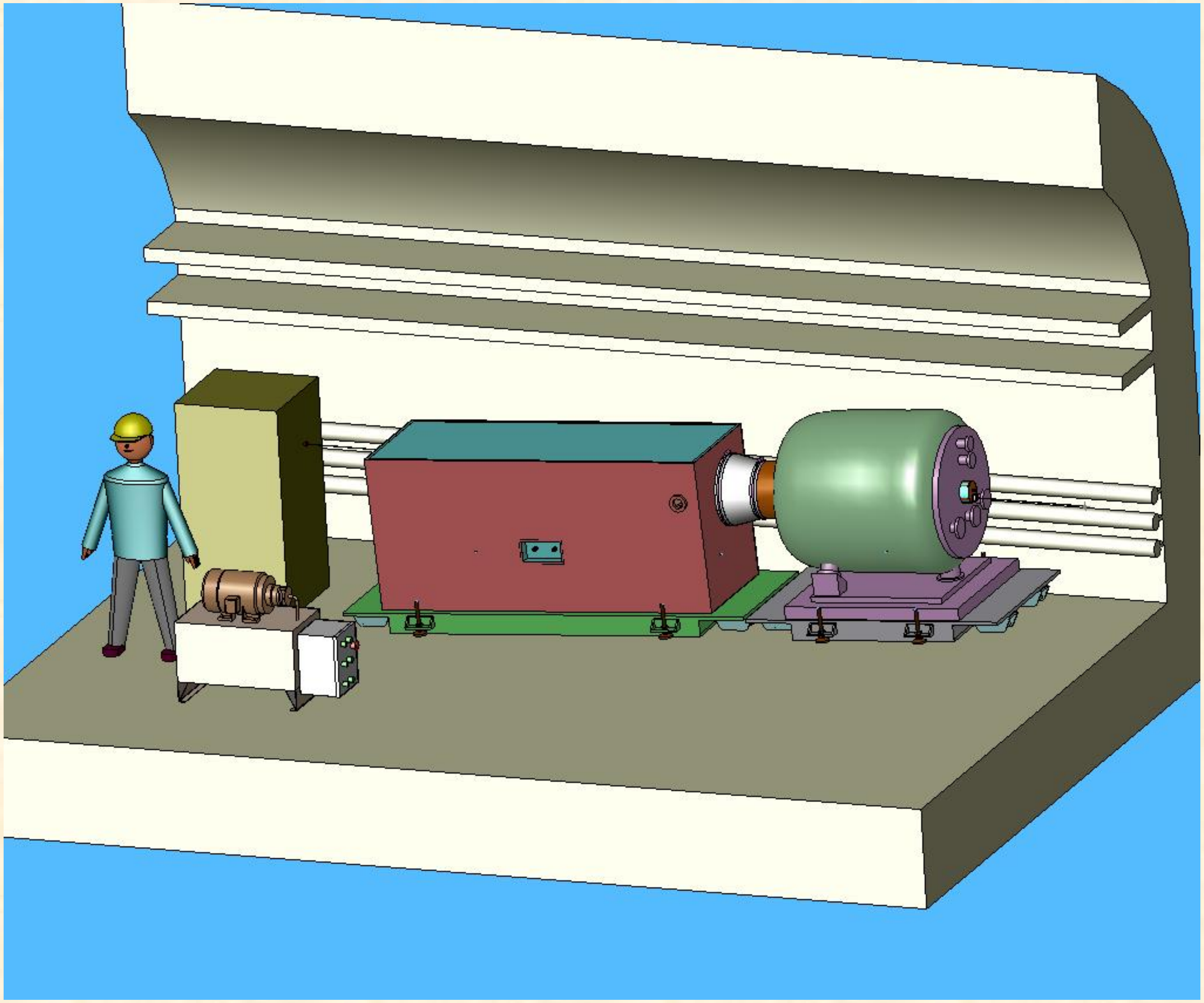
- **Piping analysis performed using AFT Fathom 5.0**
- **Results shown separately**



Recommendations

- **Change baseline Hg delivery system to syringe approach**
- **Size syringe & sump tank with capacity for 15-second jet**
- **Perform additional nozzle simulations and analyses**
- **Perform Hg flow tests to provide needed design feedback**

Syringe Layout



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