Outline for Aiman's (ODU) Dissertation work

Reduction of outgassing is critical to save the overall cost of Cosmic Explorer (the next-generation gravitational wave detector, two arms each 20 km long 1.2 m dia pipe)

Target P_ul=	**1.00E-09**	**1.00E-09**	**1.00E-10**	1.00E-11	1.00E-11	Torr
q=	1.00E-11	1.00E-12	**1.00E-12**	1.00E-12	1.00E-14	Torr.L/cm2.s
S_eff/pump=	100	100	100	100	100	L/s
D=	1.2	1.2	1.2	1.2	1.2	m
L_arm=	20	20	20	20	20	km
L=	40,000	40,000	40,000	40,000	40,000	m
A=	1.5E+09	1.5E+09	1.5E+09	1.5E+09	1.5E+09	cm^2
Q=	1.51E-02	1.51E-03	1.51E-03	1.51E-03	1.51E-05	Torr.L/s
S_req=	1.51E+07	1.51E+06	1.51E+07	1.51E+08	1.51E+06	L/s
# pumps=	**150,796**	**15,080**	**150,796**	**1,507,964**	**15,080**	pcs
Inter Pump distance=	**0.3**	**2.7**	**0.3**	**0.0**	**2.7**	m
$ pump price, per L/s	50	50	50	50	50	$
$ price/pump=	5000	5000	5000	5000	5000	$
Pump cost	**754.0**	**75.4**	**754.0**	**7,539.8**	**75.4**	**m$**

Focus: Pump-down → Huge cost (**X**)

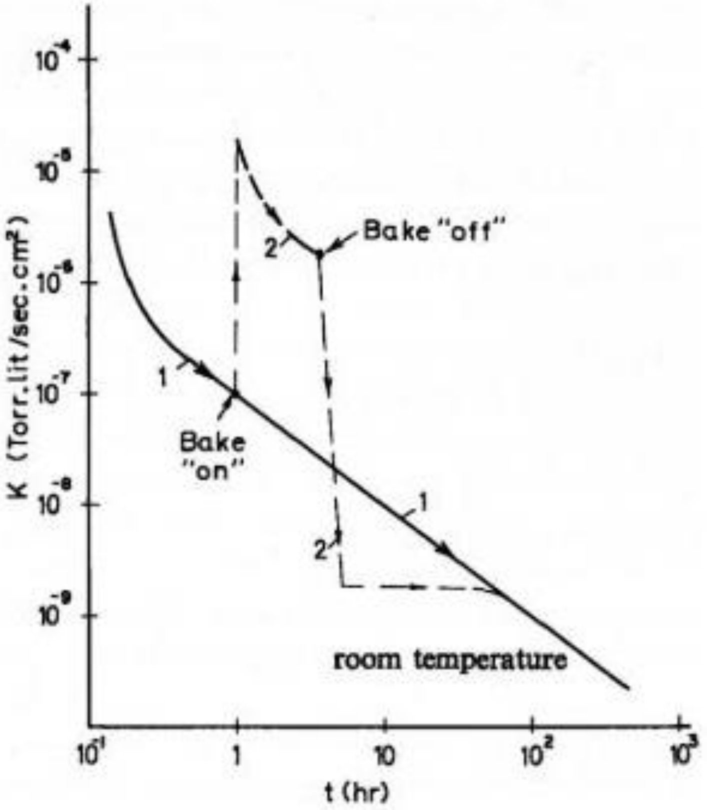
1) Pump cost
2) Bake cost
3) Operation cost (electricity)
4) Maintenance cost

Focus: Material → Cost effective (√)

1) Surface treatment cost (?)
2) Operation cost (electricity)
3) Maintenance cost

Diffusion barrier and hydrophobic coating can promise the XHV requirement achievable in a cost effective way.

- ❑ Save on baking
- ❑ Save on pumping time
- ❑ Save on pumping expense for the lifetime
- ❑ Mild steel is ~3X cheaper than SS316
- ❑ Save on operation task and cost



Aim is to identify materials (+ coating) that can promise required low outgassing with minimum surface treatment

We studied the heat treatment effect of H_2 Outgassing rate of bare and thin film coated SS304[1]. Application of surface coating can change the outgassing behavior that can benefit us

TABLE I. Uncoated chamber (SS1) bake history and corresponding outgassing rate at 20 °C.

SS304 : E_d = 14.4 kcal/mol = 0.63 eV after 250 °C bake

Bake temperature (°C)	Bake time (h)	Outgassing rate (Torr L s^{-1} cm^{-2})	E_d (kcal/mol)
250	30	$3.560(\pm0.005) \times 10^{-12}$	14.4
400	100	$1.79(\pm0.05) \times 10^{-13}$	16.4
150	30	$1.01(\pm0.05) \times 10^{-13}$	17.5
250	30	$2.79(\pm0.05) \times 10^{-13}$	15.7
150	30	$2.16(\pm0.05) \times 10^{-13}$	16.0
360	150	$1.0(\pm0.5) \times 10^{-13}$	17.3

TABLE II. Amorphous silicon coated (a-Si) chamber bake history and corresponding outgassing rates at 20 °C.

Bake temperature (°C)	Bake time (h)	Outgassing rate (Torr L s^{-1} cm^{-2})	E_d (kcal/mol)
90	30	$2.355(\pm0.005) \times 10^{-12}$	11.3
150	30	$2.138(\pm0.005) \times 10^{-12}$	11.9
250	30	$1.556(\pm0.005) \times 10^{-12}$	11.8
400	100	$3.617(\pm0.005) \times 10^{-12}$	9.4
Vented to air and PD			3.6
150	30	$2.806(\pm0.005) \times 10^{-12}$	2.9
250	30	$1.860(\pm0.005) \times 10^{-12}$	6.7

TABLE III. Chamber coated with amorphous silicon following heat treatment (SS1:a-Si) bake history and corresponding outgassing rate at 20 °C. The outgassing rate of SS1 prior to coating with a-Si was 1×10^{-13} Torr L s^{-1} cm^{-2}.

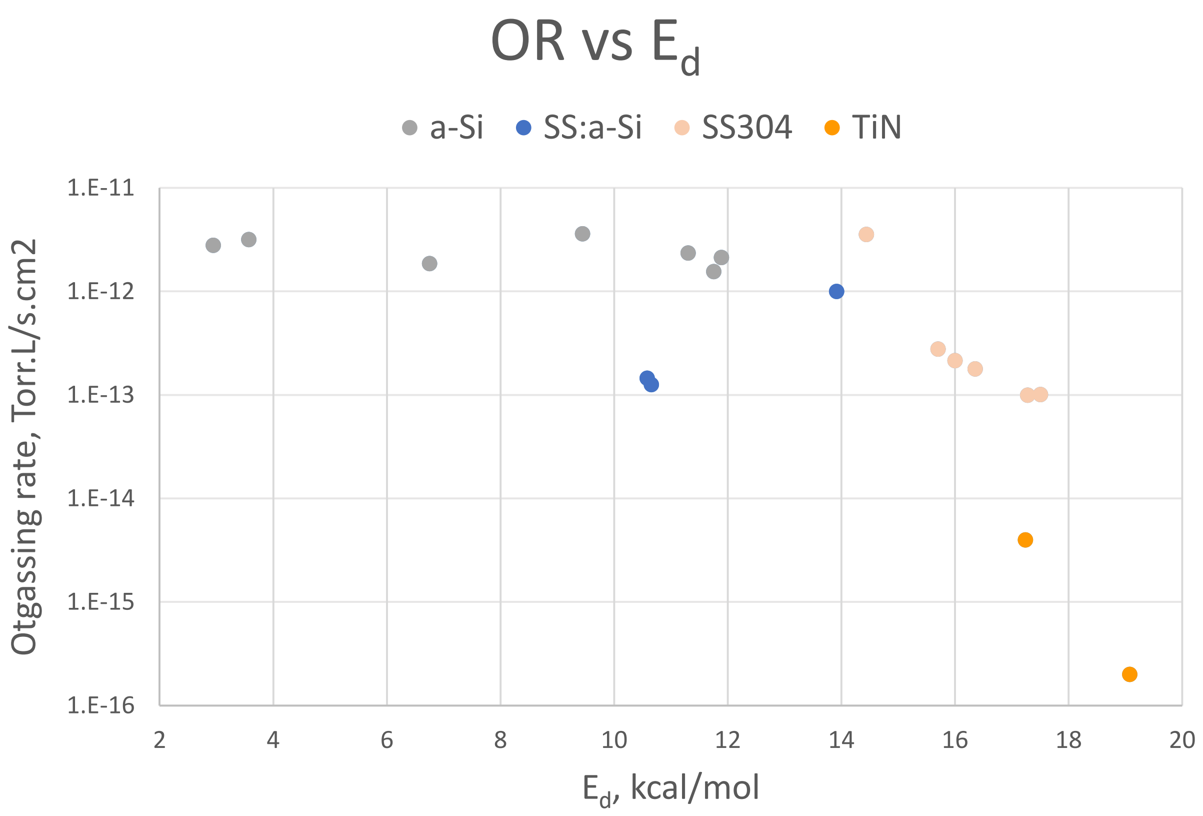
Bake temperature (°C)	Bake time (h)	Outgassing rate (Torr L s^{-1} cm^{-2})	E_d (kcal/mol)
90	30	$1.004(\pm0.005) \times 10^{-12}$	13.9
150	30	$1.26(\pm0.05) \times 10^{-13}$	10.7
250	30	$1.46(\pm0.05) \times 10^{-13}$	10.6

TABLE IV. Titanium nitride coated chamber (TiN) bake history and corresponding outgassing rate at 20 °C. Outgassing rates may be artificially low if there is any pump speed in the system, and the inhomogeneity found in the EDS analysis suggests the presence of some elemental Ti.

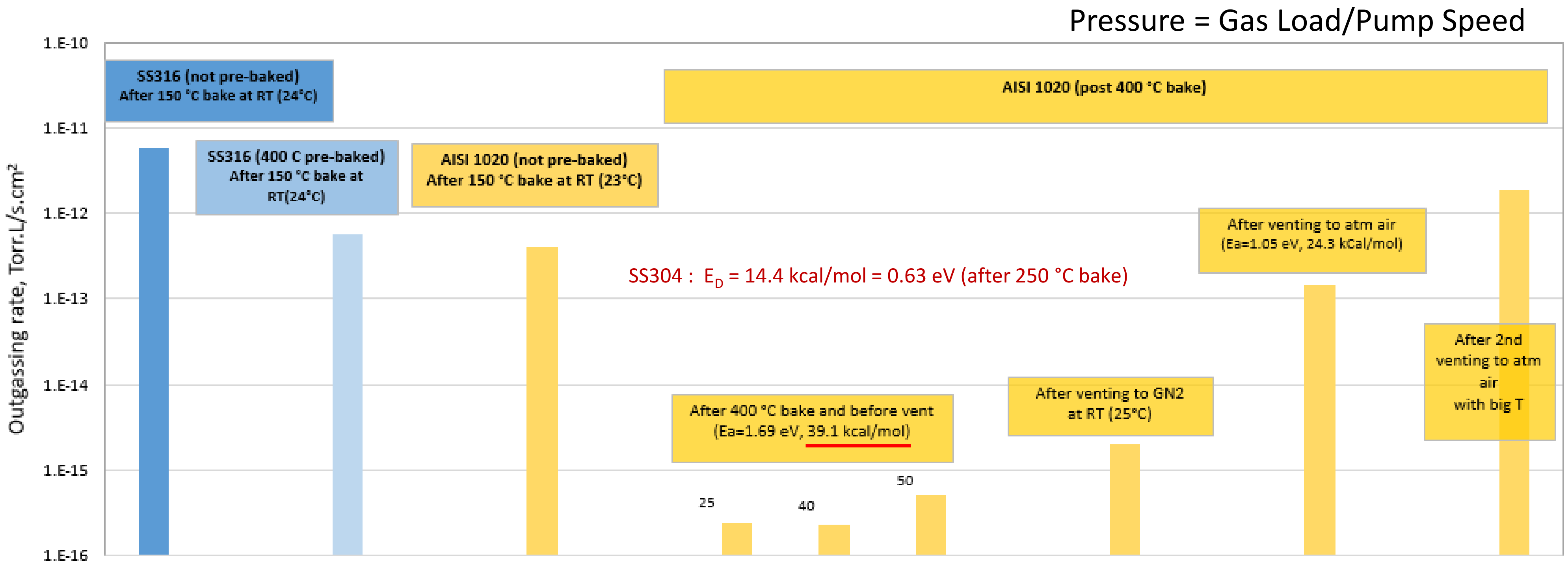
Bake temperature (°C)	Bake time (h)	Outgassing rate (Torr L s^{-1} cm^{-2})	E_d (kcal/mol)
90	30	$6.44(\pm0.05) \times 10^{-13}$	37.74
150	30	not reliable	
250	30	not reliable	
400	100	not reliable	
150	30	$4(\pm2) \times 10^{-15}$	17.2
250	30	$2(\pm20) \times 10^{-16}$	19.1

[1] Mamun et al., JVSTA 32, 021604 (2014)

Eliminating adsorbed gases that have activation energy of desorption between 10-20 kcal/mol can lead us to achieve 3-4 order reduction in ultimate pressure for SS304 material.



Cheap magnetic mild steel (AISI1020) showed lower H_2 outgassing rate than SS316

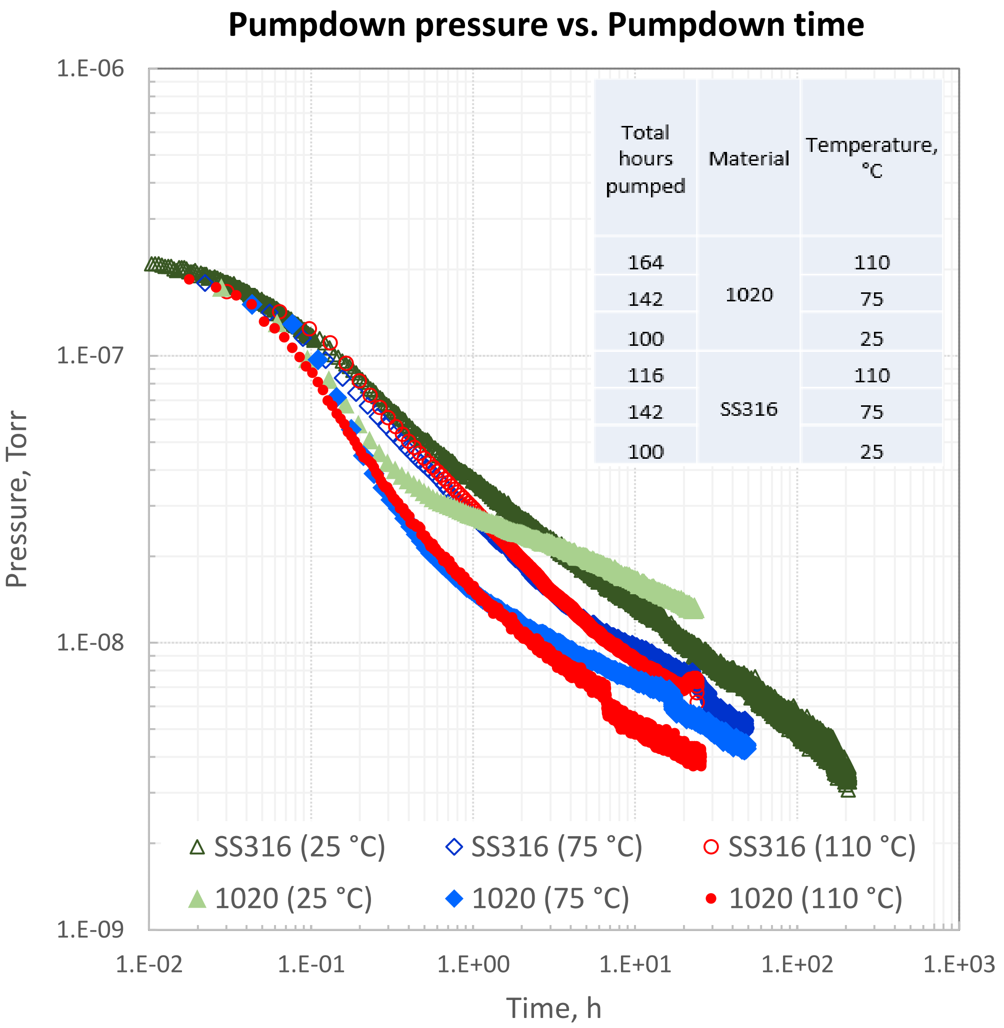


Low outgassing rate (10^{-15} Torr L/s^{-1} cm^{-2}) is critical for good vacuum (10^{-11} Torr)

- Surface with less H_2 content or high activation energy of H_2 outgassing results low outgassing rate
- Low binding energy of adsorbed gas species (H_2O, H_2, CO, CO_2 and CH_4) is desirable for achieving better vacuum and lowering pump down time, and saving on overall pumpdown cost.

Water outgassing of SS316 and AISI1020

- In low temperature heat treatment regime, water dominates the outgassing.
- We recently experimented for pumpdown from room temp to 110 °C (~ a metal can reach in a hot summer day in direct sunlight) to study the water outgassing of these two materials.
- We collected a good number of pump down measurement for water outgassing. We will apply isotherm modeling study to evaluating the binding energy of adsorbed water on mild steel and stainless steel.
- The ultimate pressure and the pump down curves from these materials did not show any significant difference in water outgassing behavior between mild steel and SS316.
- So, the bare AISI1020 will not be able to get us to low outgassing rate without moderate or high temperature bake, which is a costly avenue for a 40 km 1.2 m dia pipeline of cosmic explorer project. For JLab baking is not an issue.



Total hours pumped	Material	Temperature, °C
164	1020	110
142		75
100		25
116	SS316	110
142		75
100		25

We need to study water outgassing of metals with black surface coatings like DLC or AlTiN and explore few other things

- We need to investigate for water and hydrogen outgassing on these materials with thin film coating on these materials as well as other grades of steels.
- We did not measure water outgassing from Silco coating previously that we need to study the quick pump down nature of this coating.
- We also want to explore evaluation of binding energy and activation energy of adsorbed gas species from small test sample using surface science technique such as thermal desorption spectroscopy, and applying these parameters to model pumpdown behavior in quest of saving time spent on outgassing measurements.
- Also we want to explore induction heating over conventional bake to reduce water and hydrogen outgassing, that can save significant cost and time for cosmic explorer project.
- For photogun application, we need to evaluate abilty of de-Gaussing the magnetic chamber. Effect of annealing on the magnetic property of AISI1020
- Finally need to study modeling and simulation using CST and GPT to predict beam emittance degradation with unintended B field.

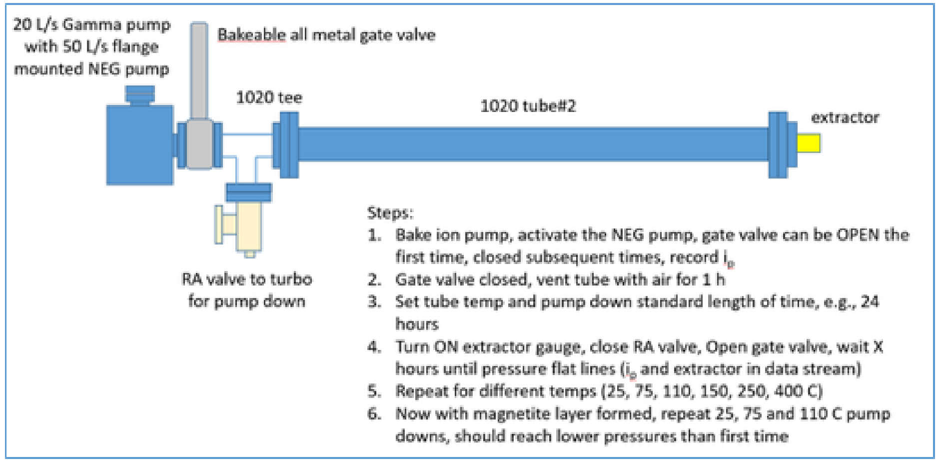
Plan for experiment

Sample Surface	AISI1020 Unbaked	AISI1020 Pre-baked	SS316 Unbaked	SS316 Pre-baked	Cost estimate
Uncoated	Pumpdown (next in queue)	Water OR (Done) H_2 OR (Done) Pumpdown (Done)	Pumpdown	Water OR (Done) H_2 OR (Done) Pumpdown (Done)	
DLC coating (Processing bake at >= 400 C)		Pumpdown H_2 OR		Pumpdown H_2 OR	2x$3K=$ 6K
Silco coating (Processing bake at >= 250 C)			Pumpdown H_2 OR	Pumpdown H_2 OR	2x$2K=$ 4K
AlTiN coating (processing bake at >= 400 C)				Pumpdown H_2 OR	1x$3K=$ 3K
Induction heater			Pumpdown H_2 OR		6+4+3=$13K : Coating cost

- Binding energy of water: isotherm modeling of pumpdown curves
- Activation energy of H2 outgassing: and OR at different temp and/or thermal desorption spectroscopy
- Study induction heater to replace conventional bake for degassing of pipes, (potential application for JLab: heat cleaning of photocathode puck)
- Demagnetization study on magnetic AISI1020
- Design a mild steel photogun chamber including electrostatic modeling and beam emittance simulation with CST and GPT
- Fabricate a mild steel photogun vacuum chamber with black outgassing barrier coating (to minimize beam hallo effect and reach better vacuum to extend photocathode lifetime)

Cost estimate for FY 2023		
Coating Cost	$13,000	
NEG pumps (3 pcs)	$6,000	Gamma NEG 50 L x 3 ≈ $6K
RAV (4 pcs)	$3,000	
Machine shop	$5,000	4 x SS316 pipes
Induction heater related	$5,000	
Brisk heater jacket	$6,000	
Miscelleneous	$2,000	
Total estimate:	$40,000	

Test Plans	Time requirement	
H_2O outgassing & pumpdown study of coated materials:	Pump down at different temps (25, 75, 110, 150, 250, 400 C) 1 wk each temp + setting up => 2 mo for each tube x 9 ≈ 18 mo / 2 set up parellel ≈ 9 mo +dat analysis ≈ 12 mo + modelling ≈ 1.5 y + manuscript ≈ 2 y Experiment = 2023 (Jan-Sep)	
H_2 outgassing study of coated materials:	Accumulation method using SRG for different RT (25-35-45-55) dP/dt measurement fot baked (75, 150, 250, 400 C) systems 1/2 wk each temp + setting up + bake => 1 mo for each tube per bake X4 ≈ 4 mo for each tube x 6 ≈ ≈ 24 mo / 2 set up in parellel ≈ 12 mo + data analysis ≈ 1.5 y + manuscript ≈ 2 y Experiment = 2023 Oct -2024 Sept	
Induction Heater:	Pumpdown study with varying time-temp approach on SS316 pipe to characterize heat cleaning efficacy Measuring H_2 outgassing rate after 150C, 250 C, and 400 C cleaning to compare with conventional bake results RGA to analyze outgassed constituents during and after heat cleaning Time frame: Bulid the set up ≈ 3 mo + characterization ≈ 9 mo + Pumpdown experiment ≈ 12 mo + H_2 OR ≈ 16 mo + data analysis ≈ 18 mo + manuscript ≈ 2 y Experiment = 2023 Jan -2024 Apr	
Light absorption & Surface characterization of coatings:	Send test coupons for coating for (3 different thicknesses if possible) and measure light absorption as a function of wavelength if possible. Nano mechanical characterization, AFM roughness, SEM-EDS, XRD, and adhesion property of the coatings on the test coupons, 9 mo + manuscript ≈ 15 mo Experiment = 2023 Apr -2023 Dec	
Pumpdown modelling:	6 mo	Expt: 2023 (Jan-Jun)
Demagnetization study of AISI1020:	8 mo + data analysis ≈ 12 mo + manuscript ≈ 18 mo	Expt: 2024 (May-Dec)
CST+GPT Simulation for beam emittance from AISI1020 photogun:	12 mo + manuscript ≈ 18 mo	Expt: 2025 Jan - 2025 Dec
Build a photogun chamber out of AISI1020	6 mo	Expt: 2026 (Jan-Jun)



Manuscripts	Time line for write ups
Candidacy/dissertation proposal	2023 (Jan-Jun)
H_2O and H_2 outgassing of AISI1020 vs SS316	2023 (Jul-Dec)
H_2O outgassing & pumpdown study of coated pipes	2024 (Jul-Dec)
H_2 outgassing of coated pipes	2025(Apr-Sep)
Simulation of beam emittance for AISI1020 photogun	2026 (Jan-Jun)
Dissertation	2026 (Jul-Dec)

Tasks	**Timeline**	**Task Category**	**Duration**
Writing: Candidacy/dissertation proposal	2023 (Jan-Jun)	Writing	6 mo
Modeling: Pumpdown modelling uncoated materials	2023 (Jan-Jun)	Modeling	6 mo
Pumpdown characterization of coated materials	2023 (Jan-Sep)	Experiment	9 mo
Build and characterize induction heater	2023 (Jan-Sep)	Experiment	9 mo
Light absorption & Surface characterization of coated materials	2023 (Apr-Dec)	Experiment	9 mo
Writing: H_2O and H_2 outgassing for uncoated AISI1020 vs SS316	2023 (Jul-Dec)	Writing	6 mo
Learn CST simulation	2023 Jul-2024 Mar	Simulation	9 mo
Pumpdown data analysis of coated materials	2023 (Oct-Dec)	Analysis	3 mo
H_2 outgassing rate study of coated pipes	2023 Oct -2024 Sept	Experiment	12 mo
Induction heater for SS316 pump down and H_2 outgassing rate study	2023 Oct-2024 Apr	Experiment	7 mo
Modeling: Pumpdown modelling for coated materials	2024 (Jan-Jun)	Modelling	6 mo
Induction heater data analysis	2024 (Apr-Jun)	Analysis	3 mo
Learn GPT simulation	2024 Apr- 2024 Dec	Simulation	9 mo
Demagnetization study of AISI1020	2024 (May-Dec)	Experiment	8 mo
Writing: H_2O outgassing and pumpdown study of coated pipes	2024 (Jul-Dec)	Writing	6 mo
H_2 outgassing rate data analysis of coated materials	2024 Oct- 2025 Mar	Analysis	6 mo
CST+GPT Simulation for beam emittance from AISI1020 photogun	2025 Jan - 2025 Dec	Simulation	12 mo
Writing: H_2 outgassing rates of coated pipes	2025(Apr-Sep)	Writing	6 mo
Writing: Simulation of beam emittance from AISI1020 photogun	2026 (Jan-Jun)	Writing	6 mo
Build a photogun chamber out of AISI1020	2026 (Jan-Jun)	Experiment	6 mo
Writing: Dissertation	2026 (Jul-Dec)	Writing	6 mo