Cryogenic Liquid Safety for the DEAP-3600 Experiment

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for the DEAP-3600 Collaboration

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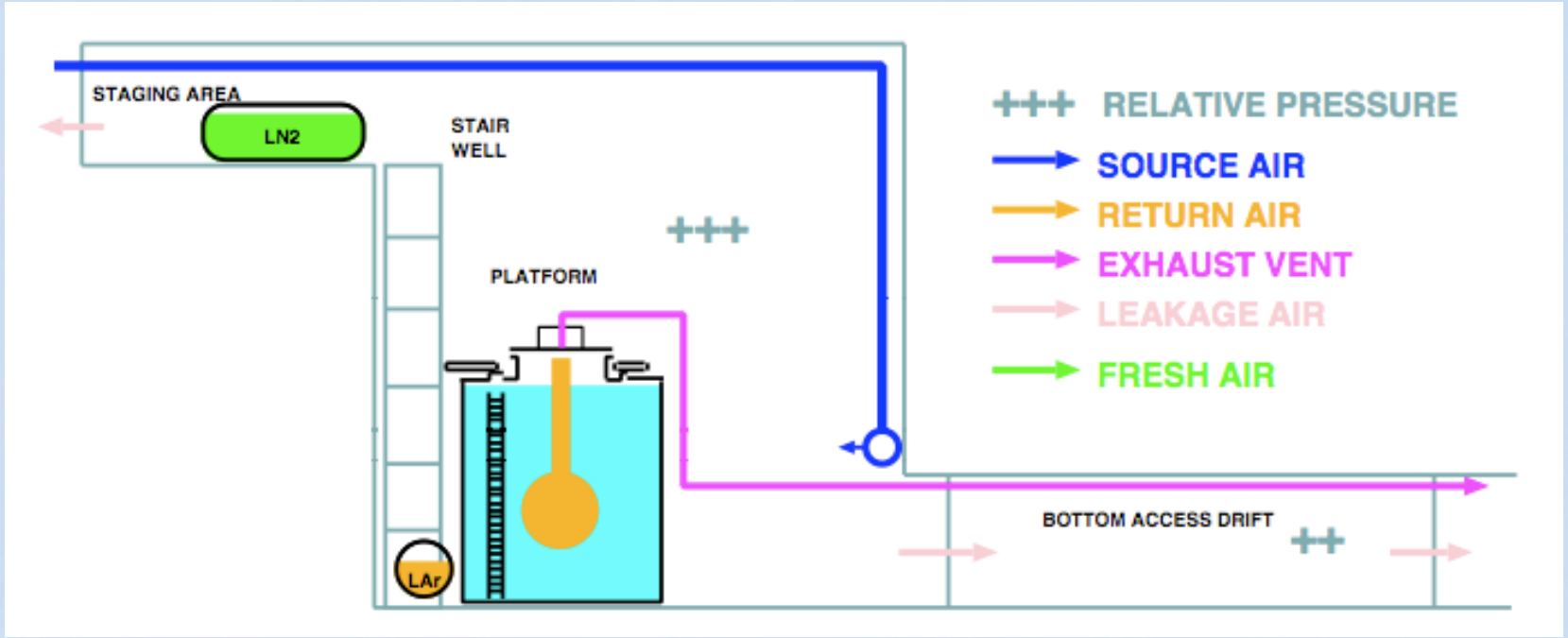
Cryogenic Liquids in the SNOLAB Cube Hall

Component	Volume (m^3)	Displaced Volume (m^3)	Fraction of Cube Hall (%)
Cube Hall Air Volume	4967	-	-
DEAP LN_2 Inventory	2.6	1541	31
DEAP LAr Inventory	2.9	2029	41
MiniCLEAN LAr Inventory	1.8	1200	24
Standard Gas Bottle	0.05	8	0.2



Oxygen Deficiency

Partial Pressure of Oxygen (mmHg)	Concentration at 1 Atm (%)	Concentration at 17.3 psia (%)	Effects
188	-	21	Nominal SNOLAB conditions
160	21	-	Nominal surface conditions
129	17	15	Night vision reduced Increased breathing volume Accelerated Heartbeat
122	16	14	Dizziness Reaction time for novel tasks doubled
114	15	13	Impaired attention Impaired judgement Impaired coordination Intermittent breathing Rapid fatigue Loss of muscle control
91	12	11	Very faulty judgement Very poor muscular coordination Loss of consciousness Permanent brian damage
76	10	9	Inability to move Nausea Vomiting
46	6	5	Spasmatic breathing Convulsive movements Death in 5-8 minutes

Adapted from Argonne National Laboratory Physics Division Cryogenic Safety Manual

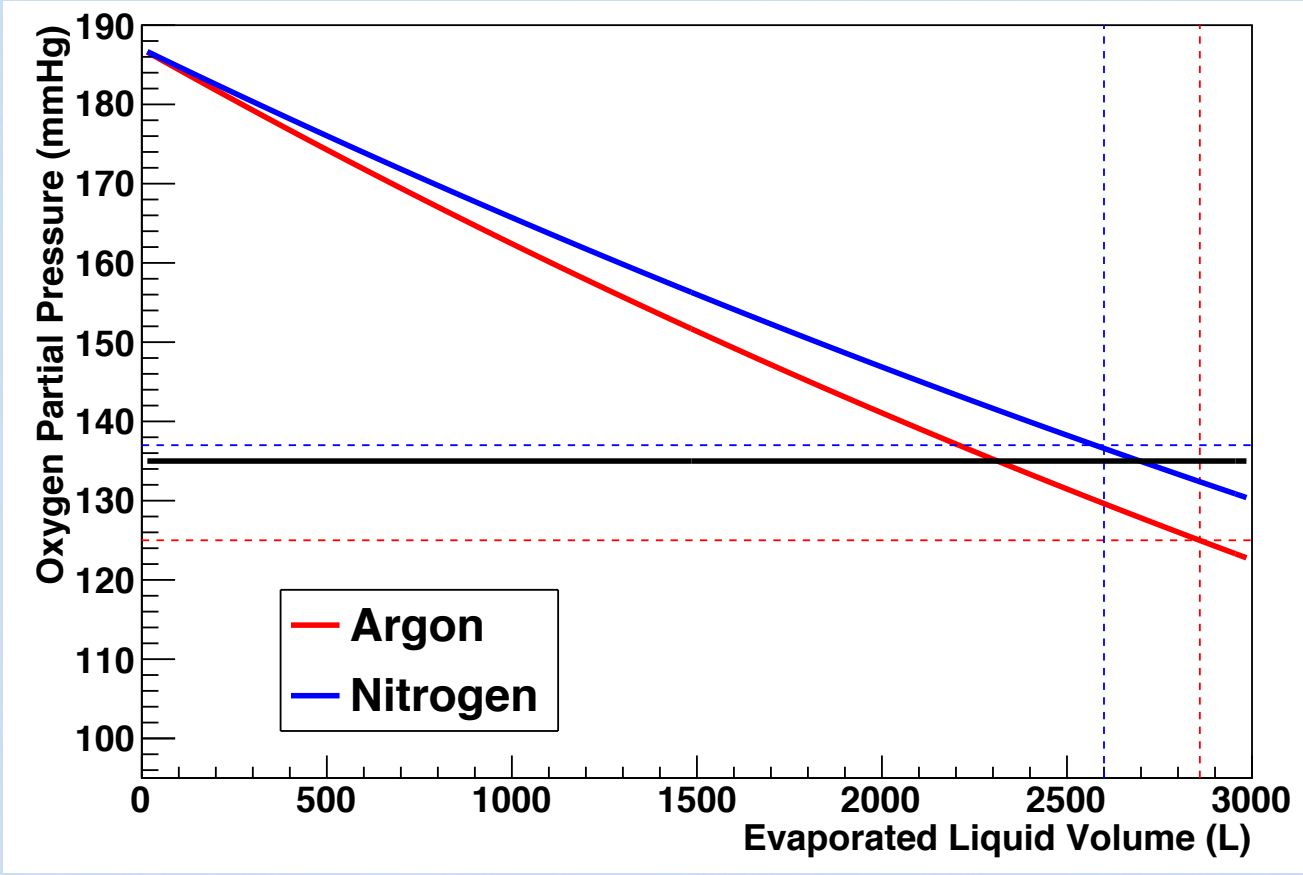
Safety Strategies

1. Engineer to Prevent Release
   - Closed-loop cooling system
   - Certified pressure vessels
   - Industry standard vacuum jacketed piping
   - Seismic isolators
2. Exhaust to Safe Area
   - Exhaust through 12” aluminum pipe to mine air raise
   - Important during power outages
3. Ventilate
   - Force mixing of gas in hall
4. Alarm and Evacuate
   - Multiple oxygen monitors
   - Evacuate + rectify remotely
   - Training

Ventilate Using Air in Cube Hall

DEAP Nitrogen Inventory

DEAP Argon Inventory



135 mmHg Safe Limit

with perfect gas mixing

Ventilation

- Without gas mixing, smaller spills become dangerous
- Can’t rely on diffusion or natural convection
- Force mixing using large fans

Exhaust Pipe Sizing

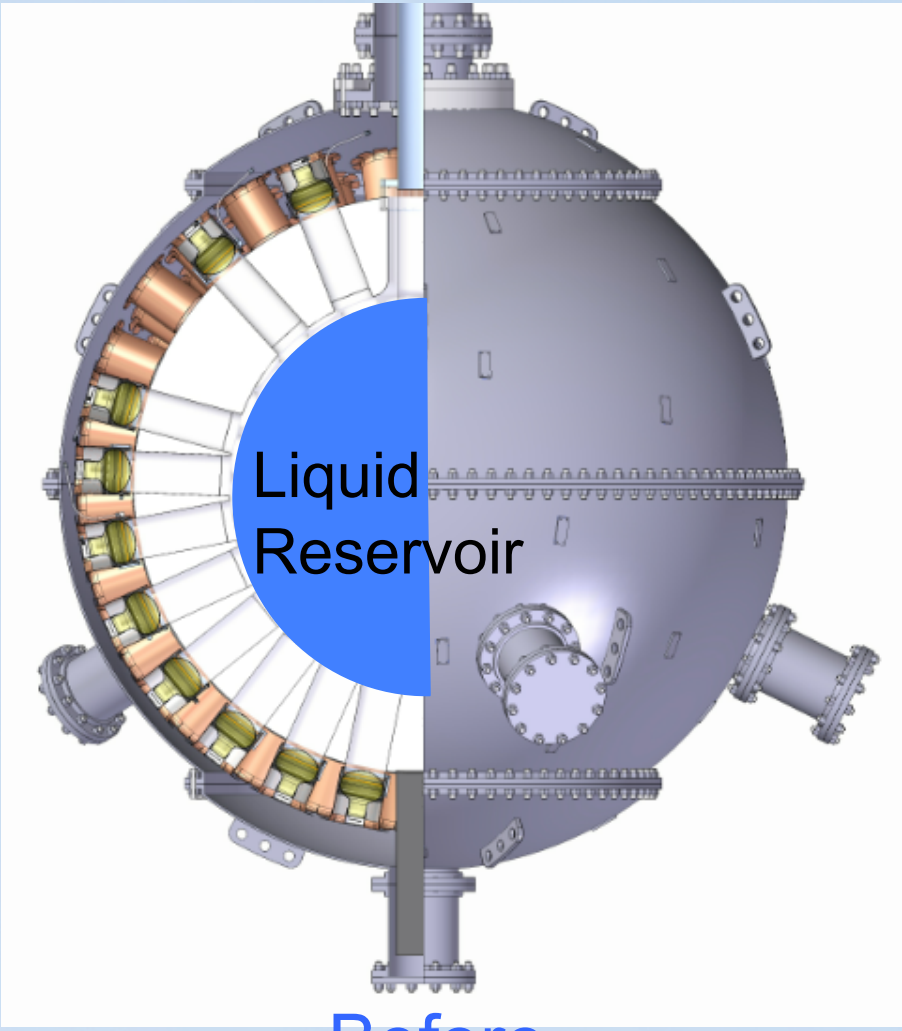
- Highly non-standard cryostat
  - Expect very high vapour generation if AV fails
- Pipe will be roughly 400 m long with multiple bends
  - Significant flow resistance
- Goal: size pipe to handle maximum vapour release rate with a reasonable pressure drop
  - Around 15 psi

Calculation Method

1. Estimate properties of surfaces in contact with LAr
   - Materials
   - Area
   - Mass
   - Temperature
2. Estimate boil-off rate for surfaces
   - Measure boil-off from small warm samples
   - Scale up measurements
3. Estimate gas flow through pipes and PSVs
   - Estimate gas released to hall
   - Estimate pressures in piping and Steel Shell

Design Event

- DEAP acrylic vessel (AV) breaks, releasing liquid argon (LAr)
- LAr instantly drains to fill steel shell to liquid equilibrium line
- Evaporated argon travels up the neck, through a long vent line, and into the Vale air raise
- Extremely conservative event



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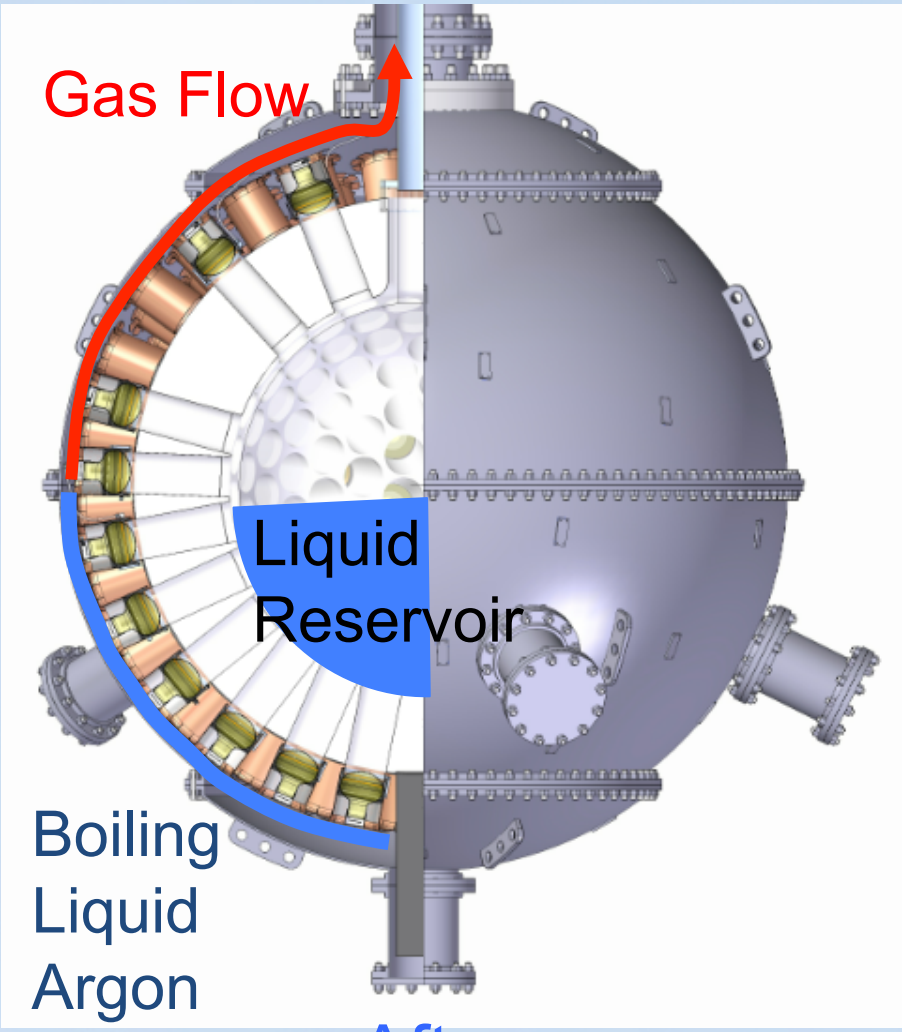
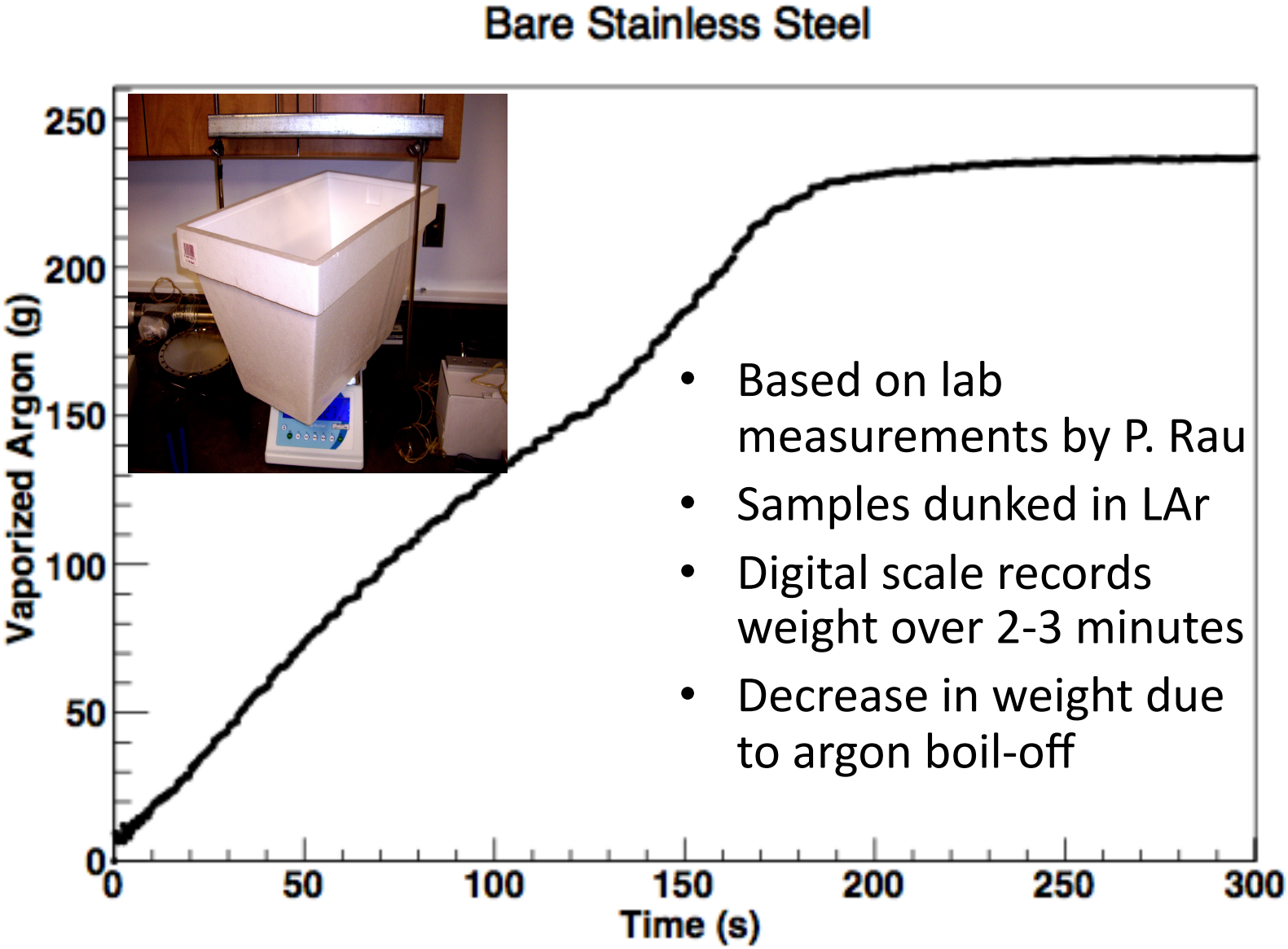


Wetted Area Budget

Wetted Area Budget

Assembly	Component	Material	Below Equator	
			Exposed Area (m^2)	Mass (kg)
Gaps Between Filler Blocks and Light Guides	Light Guides	Acrylic	36.2	-
	Filler Block Sides	HDPE	48.5	1230
		Foam	12	10
	AV Support Blocks	Acrylic	0.8	43
Back of Filler Blocks	Filler Block Backs	HDPE	7	-
	Filler Block Hardware	Stainless Steel	~1.9	35
	Filler Block Springs	Stainless Steel	~7.3	40
	Filler Block Insulation	Foam	~54	79
PMT Assemblies	PMT Mounts	PVC	2.8	139
	PMT Glass	Glass	2	-
	PMT End Cap	Plastic	4.4	-
	Thermal Shorts	Copper	~46.8	251
	LG Band Clamp	Stainless Steel	~3.9	29
	PMT Band Clamps	Stainless Steel	~2.6	26
	PMT Mount Springs	Stainless Steel	~1.3	3
	PMT Oil Tubing	HDPE	~4.8	10
	Oil Tubing Fittings	Stainless Steel	~1.8	22
Cables	PMT Cables	-	~7	~14
	Other Cables	-	4?	2?
Steel Shell	Steel Shell	Stainless Steel	~19.8	-
	AV Support Assemblies	Stainless Steel	1	100

Vapour Generation Estimation



Vapour Generation Estimation

Scaled Data Method

- Directly scale measurement data by
  - Area
  - Number of Parts
  - Mass
- No data for cold plastics
- Good for warm metal parts

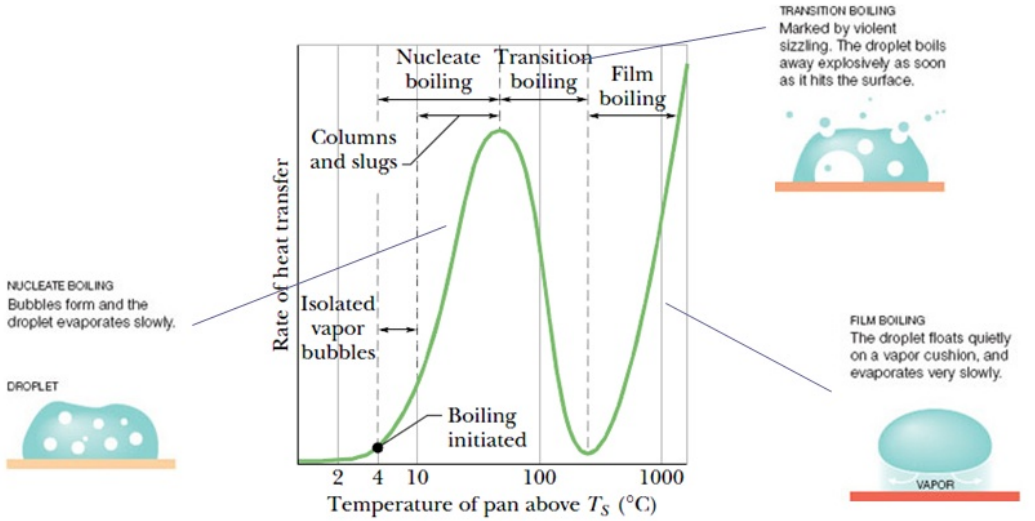
Analytic Model Method

- Model heat transfer to predict generation
- Depends on
  - Area
  - Mass
  - Temperature
  - Materials properties
- Use measurements to tune model
- Good for cold plastics

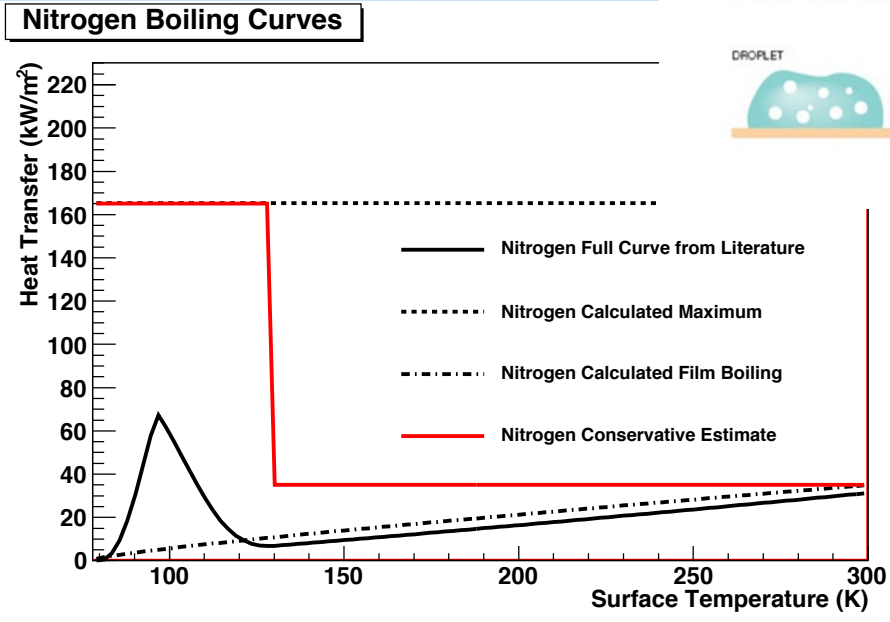
Analytic Model Method

Heat transfer for water (@ 1 atm)

S-shaped graph when heat flux (q") is compared to temperature.

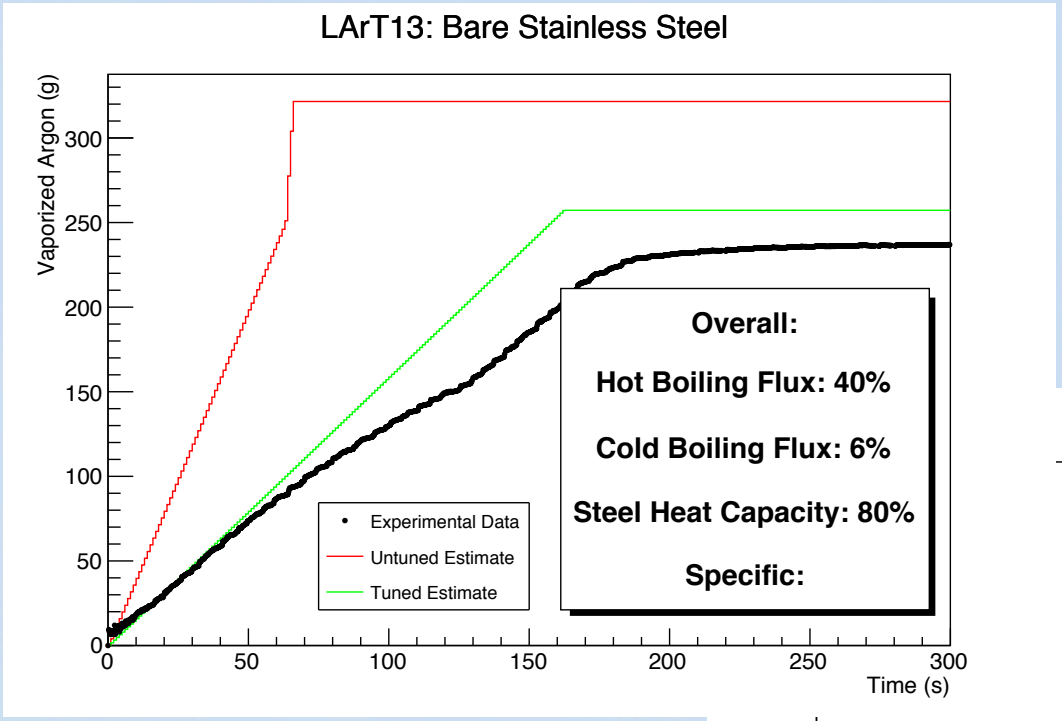


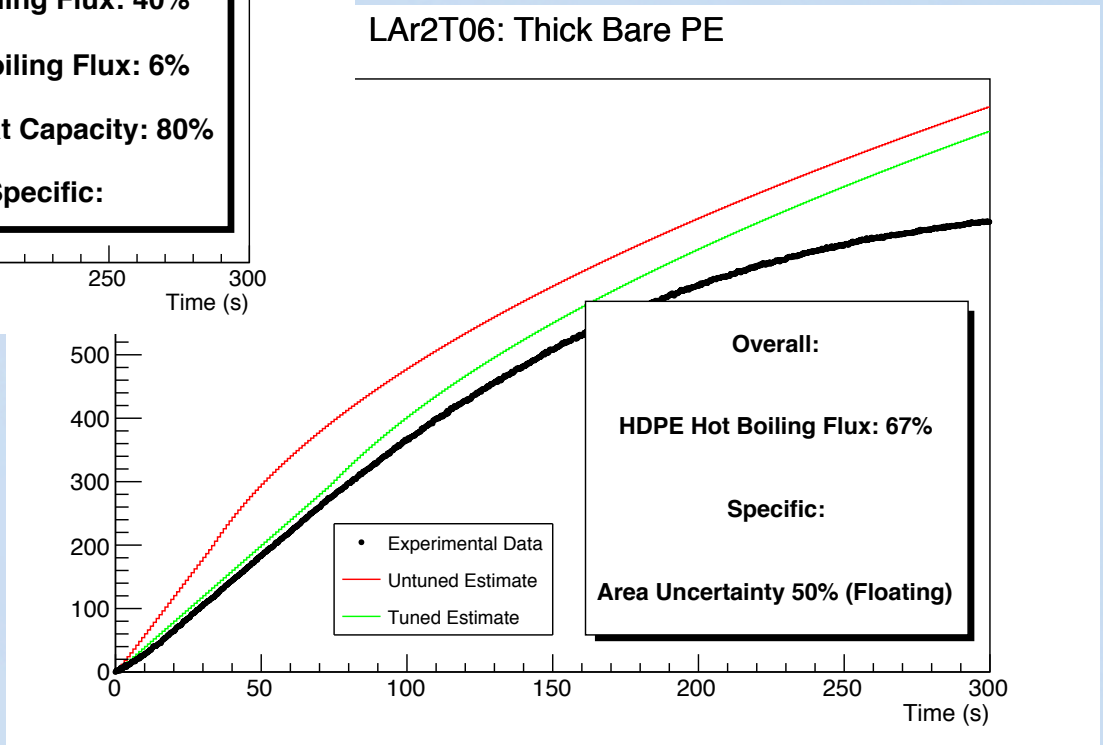
Source: wikipedia



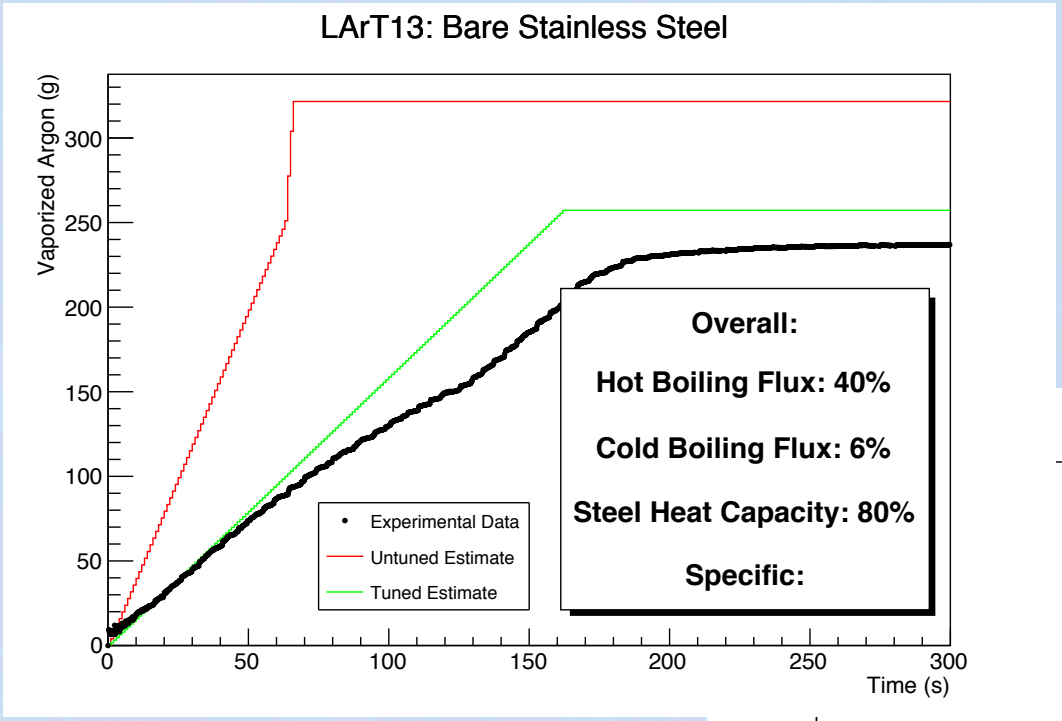
Data: Jin et.al. J Zhejiang Univ Sci A, 10(5), 2009

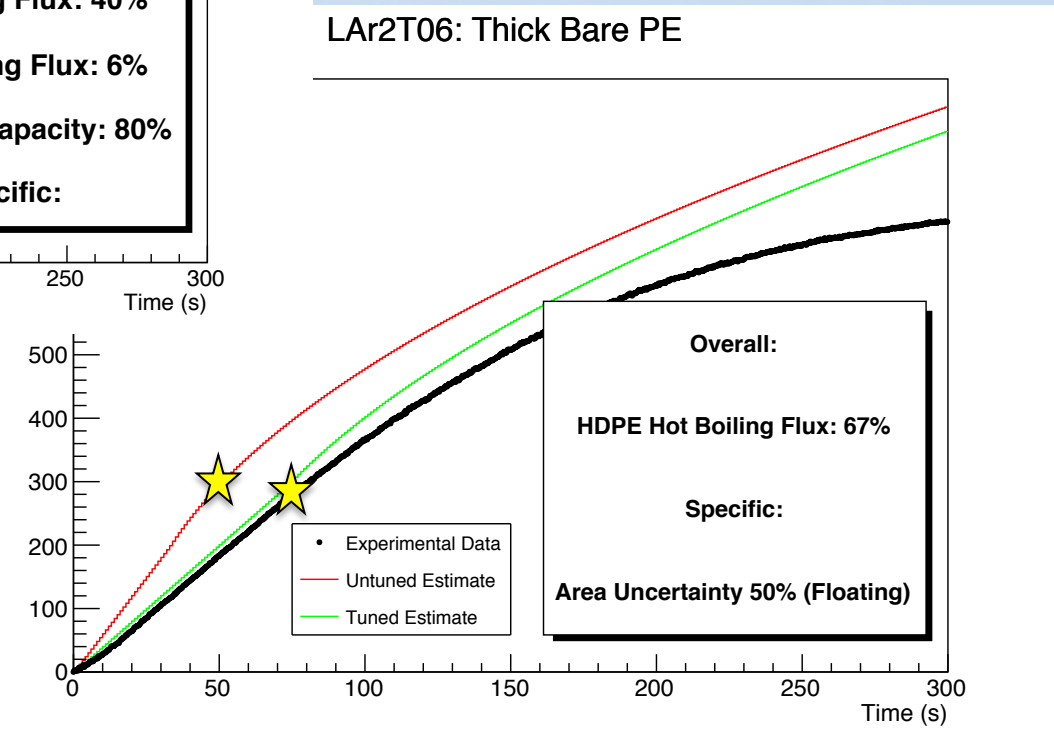
Analytic Model Method





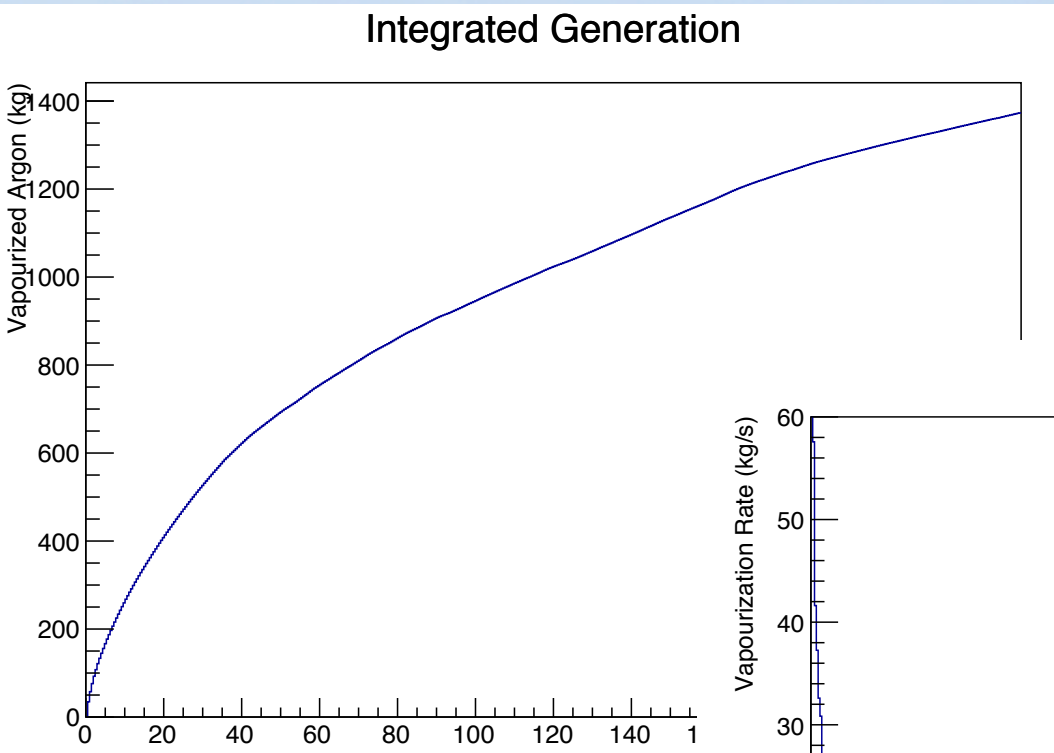
Analytic Model Method

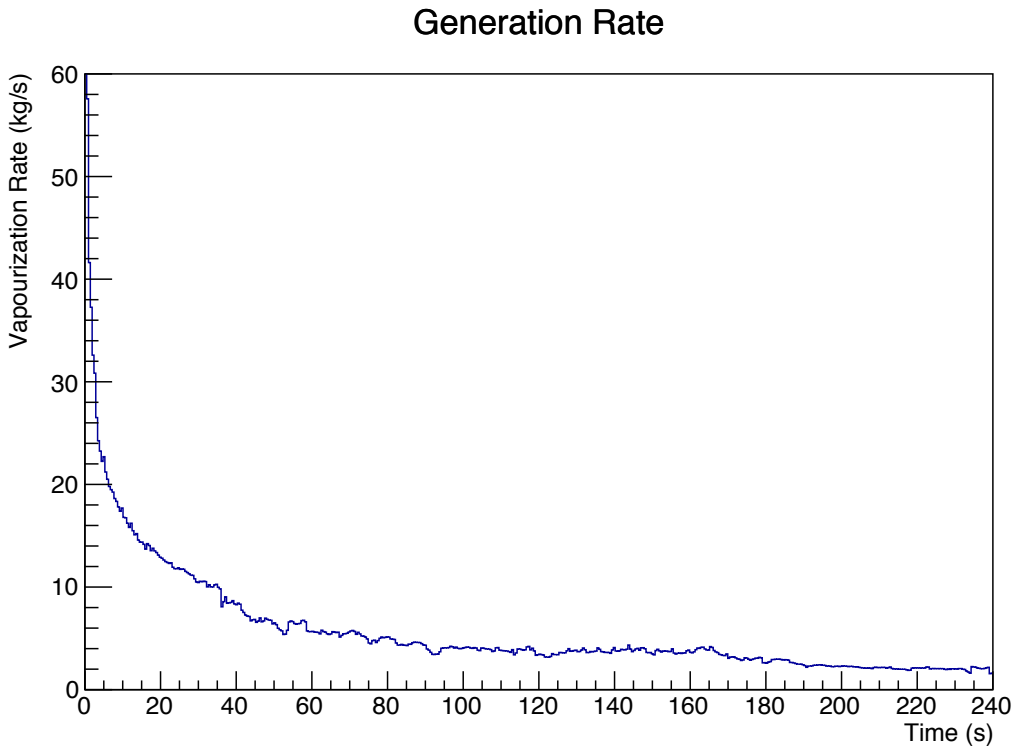




★ Transition from vapour-dominated to conduction-dominated

Total Vapour Generation Estimate

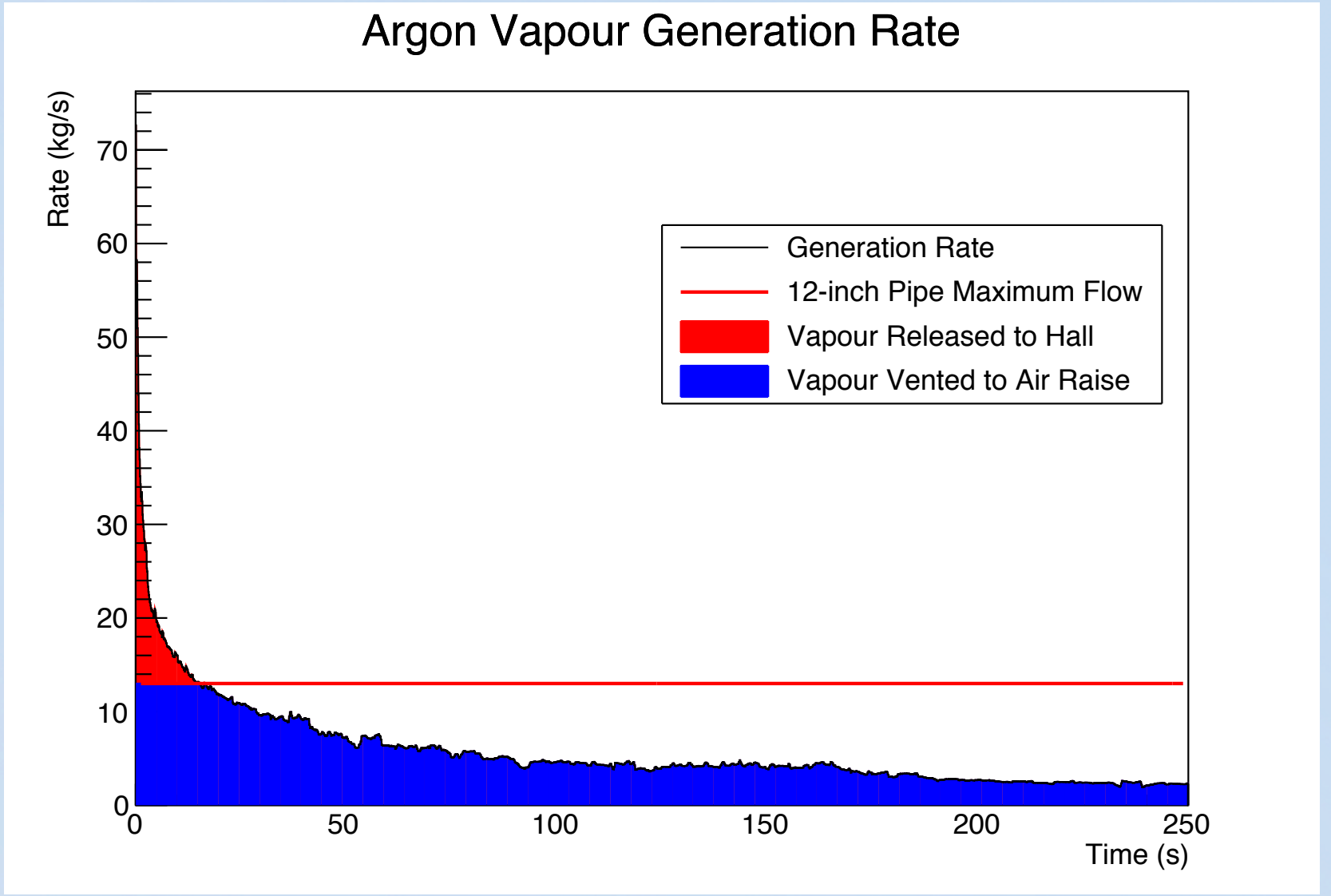




Vapour Generation Budget

Component	Estimation Method	Mass Released (kg)	Percentage
		At 3 Minutes	
Light Guides	Analytic	168	14
Filler Blocks	Analytic	487	39
Insulation	Analytic	121	10
Steel Fitttings	Scaled Data	55	4
Steel Shell	Scaled Data	198	16
Copper	Scaled Data	62	5
PMT Cables	Scaled Data	14	1
Other	Both	135	11
		1240	100

In worst-case scenario, 1/3 of LAr target evaporates within 3 minutes



Use a large-diameter pressure relief valve to prevent explosion. Around 300 kg of argon gas released, oxygen partial pressure stays above 170 mmHg.

Summary

- DEAP is engineered to prevent the release of argon and nitrogen
- Gas releases will be routed to the mine air raise
- The exhaust line is designed to handle a worst-case failure with a reasonable gas release to the hall
- Mixing fans ensure that work spaces are well-ventilated
- Alarms and training provide another layer of protection