Critical Factors for SF_6 Replacement Cover Gases

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SF_6 Replacement Cover Gases

- Choices
  - SO_2
  - Novec™ 612 (FK-12)
  - AMCover™ (HFC-134a)
  - CO_2, others
- Criteria
  - Performance, Economics, Regulatory Future
  - Process, Equipment, Facility Details

Critical Cover Gas Factors

- Cover Gas Formulation
  - Carrier Gases
  - Moisture
- Agent Concentration/Cover Gas Flow Rate
- Gas Distribution over the melt
- Process Flow Controls
  - Replacement of Lost Gas during process operations

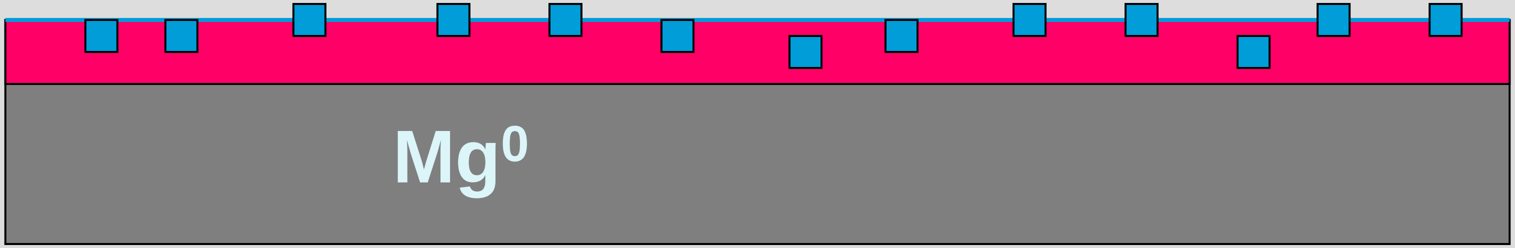
Formulation

Agent + Carrier Gas

- **Carrier gas needs to**
  - **Dilute CGA to the needed concentration**
  - **Provide oxygen to form protective film on Mg**
  - **Be readily available and cost effective**

SF_6 Protection of Molten Mg

$Mg^0 + O_2 \longrightarrow$ MgO

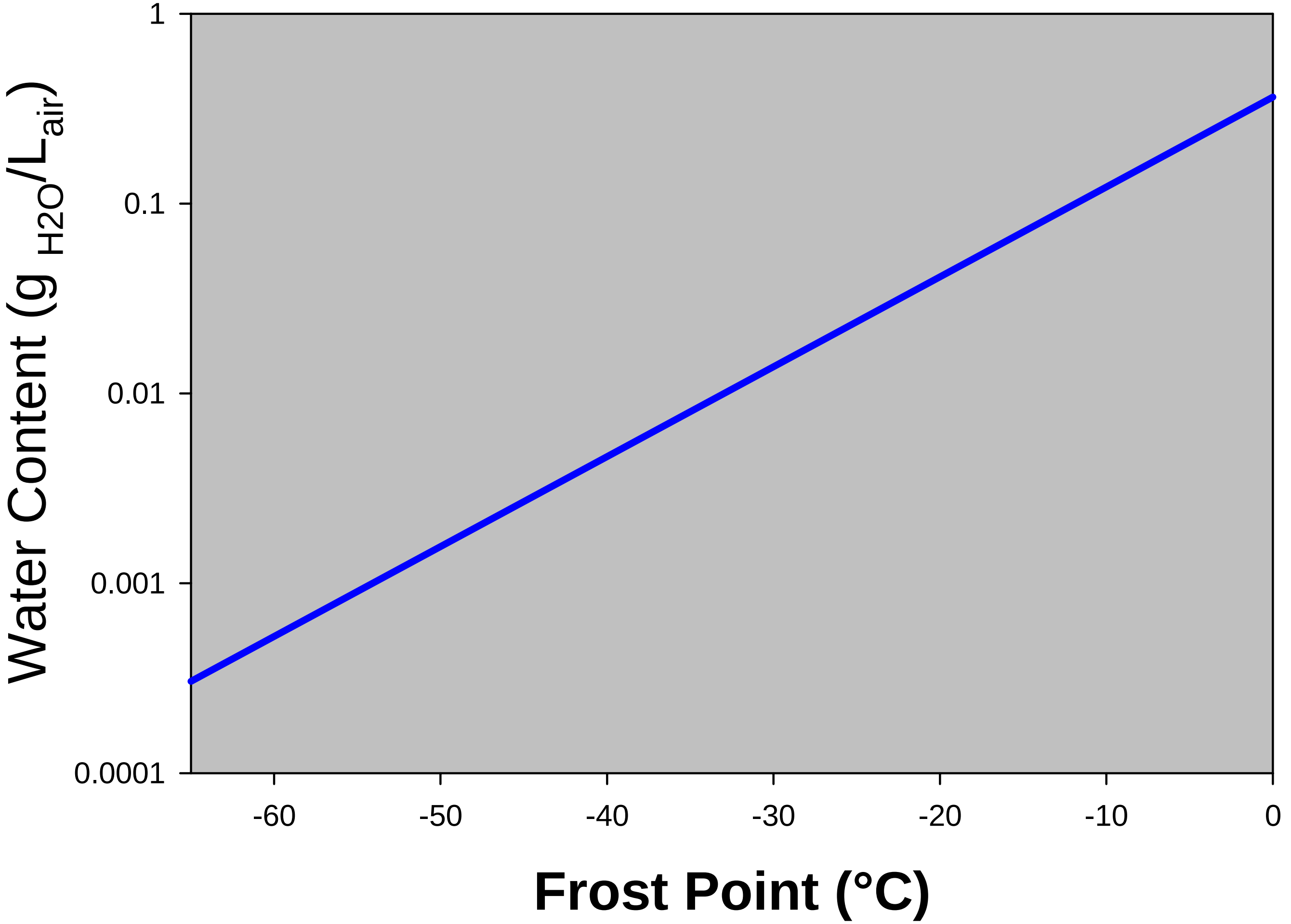


$Mg^0 + SF_6 \longrightarrow$ "MgF_2"

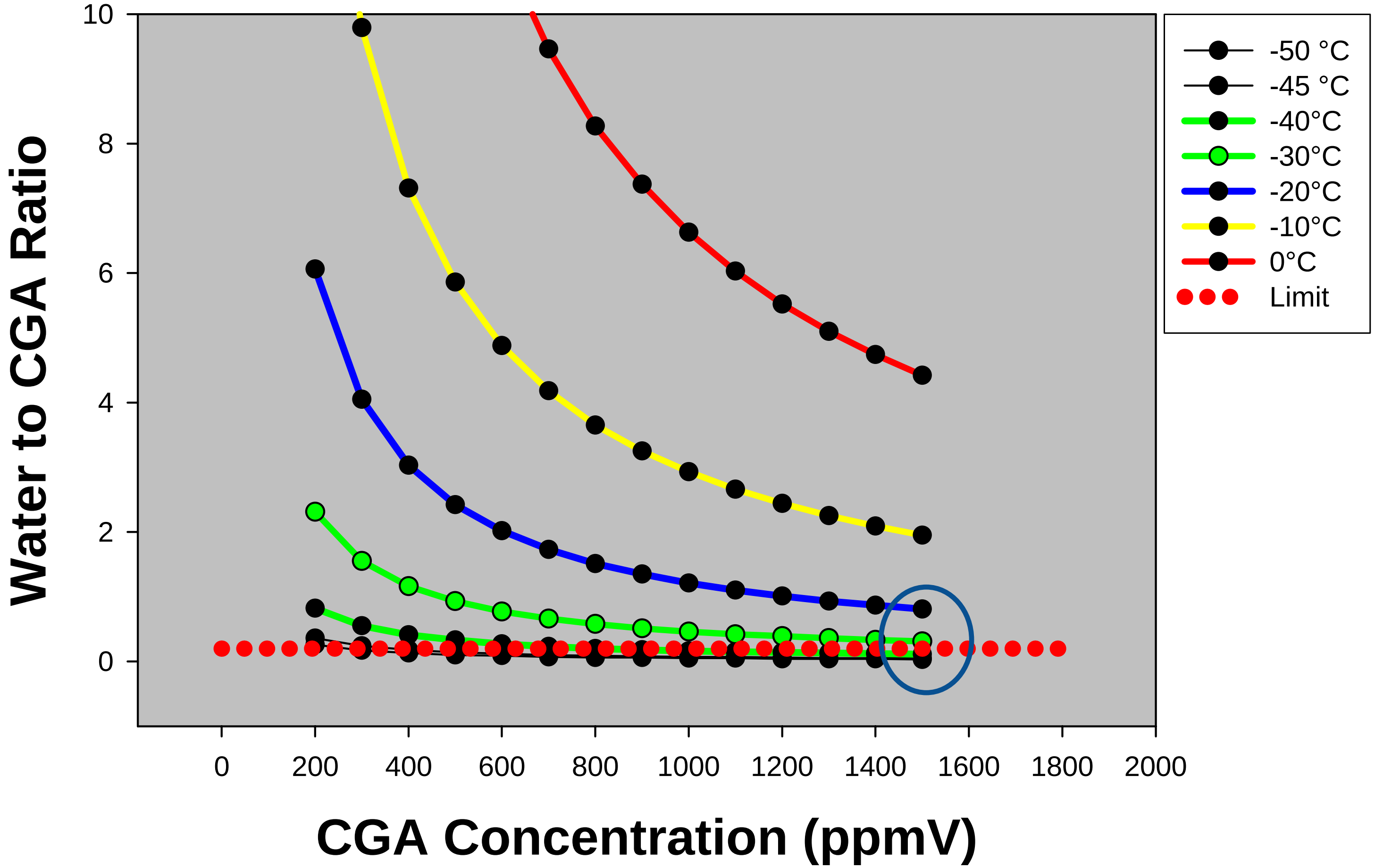
Formulation

- **Agent + Carrier Gas**
- **Options – Air, N_2, CO_2 mixtures**
  - **Air (O_2) is needed to form protective surface film over molten magnesium**
  - **But Air contains water**
- **How dry is dry air?**

Water Content of Air



Ratio of Water to CGA at Decreasing Frost Points



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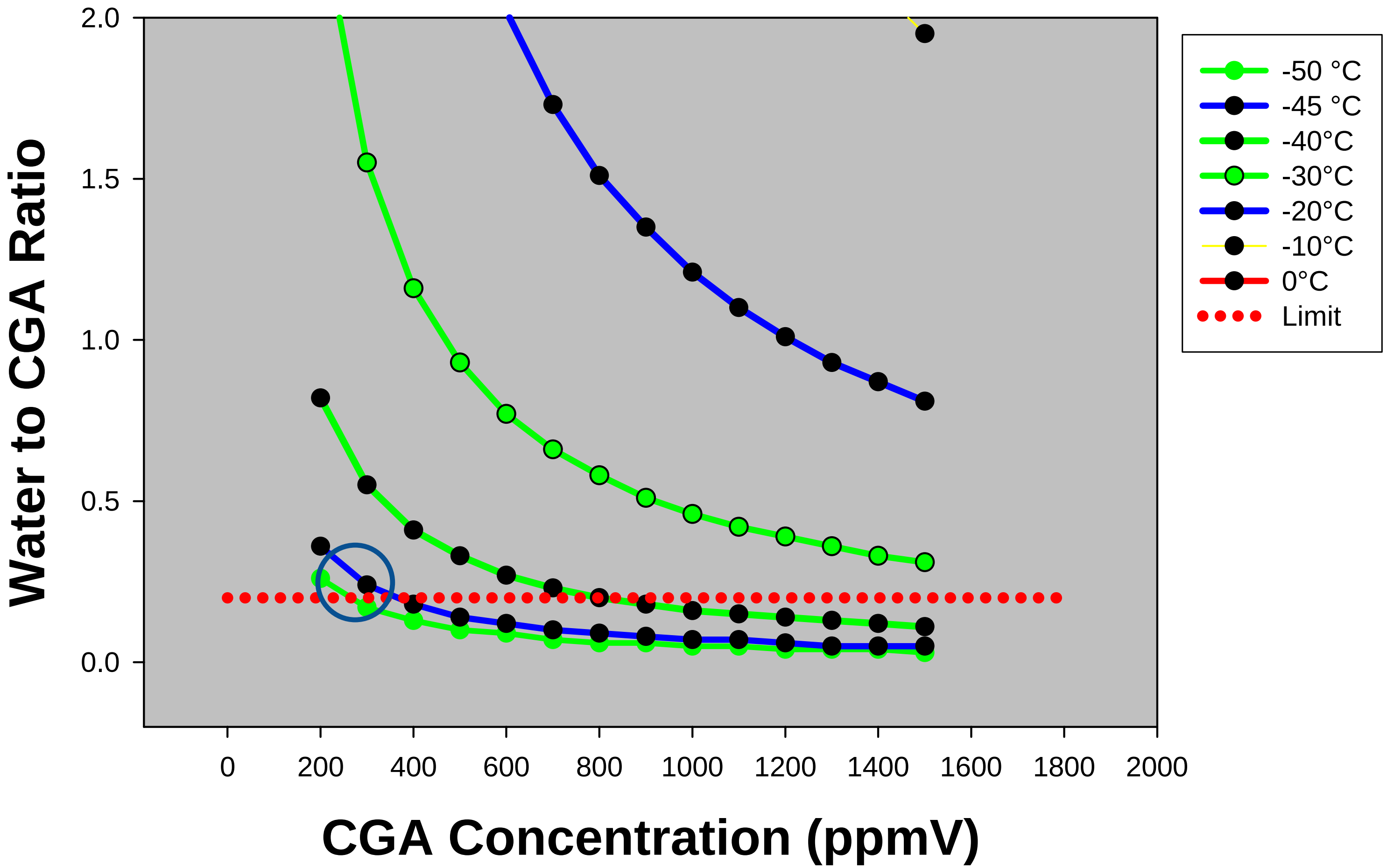

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Formulation

- Agent + Carrier Gas
- Options – Air, N_2, CO_2 mixtures
    - Air (O_2) is needed to form protective surface film over molten magnesium
    - But Air contains water
        - Reacts with Mg to form MgO (white dust)
        - Destroys agents (Need to use substantially more CGA)
        - Produces acid: Corrosion, possibly health concerns
  - SF_6 Replacement agents don't work well with air

Formulation

- Agent + Carrier Gas
- Options – air, N_2, CO_2 mixtures
  - Generally available dry (bulk liquid N_2) or from a nitrogen generator

    N_2 generator requires clean dry air as input
  - Requires an oxygen source
    - Ambient air, N_2/O_2 mixture from an N_2 generator
  - Surface films with N_2 are more porous
    - Requires more CGA

Formulation

- **Options – air, N_2, CO_2 mixtures**
  - **CO_2 works with all agents**
    - **Dry, readily available**
    - **Oxygen source for MgO**
    - **Forms a “tight” film and reduces the amount of CGA needed**
      - **Virtually eliminates MgO dust in workplace**

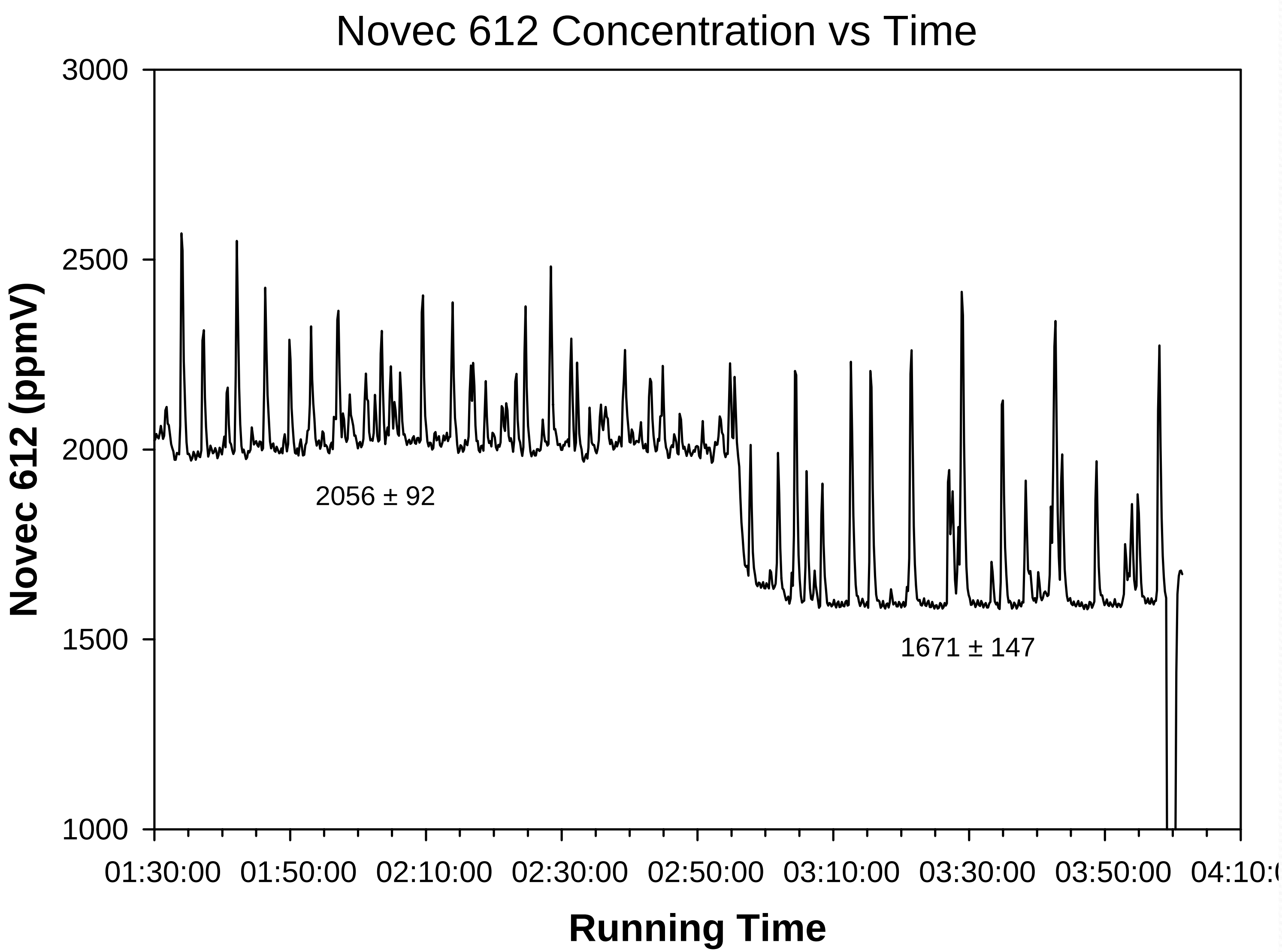
    - Reaction can form CO in large amounts if not used properly
      - **$Mg + CO_2 \rightarrow MgO + CO$**
      - **Excess CO if not enough agent available**
      - **Blue flames, excess dross, worker exposure**

Formulation

Ideally carrier gas is mixture of CO_2 /air or N_2 /air

- With CGA, this is a three gas mixture which is difficult to control
- Generally requires new gas mixer
  - Best with PLC control

Isolate gas mixer from process (pressure drops/spikes)



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Concentration/Flow Rate

Critical to deliver the correct amount of CGA to the melt surface

Combinations of concentration and flow rate can be used

- Flow Rate (L(gas)/min) x Concentration (L(CGA)/L(gas)

0.2% SF_6 at 30 LPM (0.002 X 30 = 0.06LPM SF6)
0.5% SF_6 at 12 LPM (0.005 x 12 = 0.06 LPM SF6)
0.05% SF_6 at 120 LPM (0.0005 x 120 = 0.06 LPM SF6)

Concentration/Flow Rate

High Conc – Low flow is commonly used for SF_6

- Fewer volume changes over the melt
  - Even distribution - Little SF_6 reaction and diffusion
  - Requires a "tight" lid on furnace
  - Low tech gas mixers (Fixed orifice, rotameters) work well enough

Doesn't work well for replacement CGAs

- Replacement gases react more quickly than SF_6
  - Requires more CGA and increases costs and emissions

Concentration/Flow Rate

Novec 612™ and AmCover™ are very reactive at melt temperatures

Higher flow rates and lower concentrations are more effective

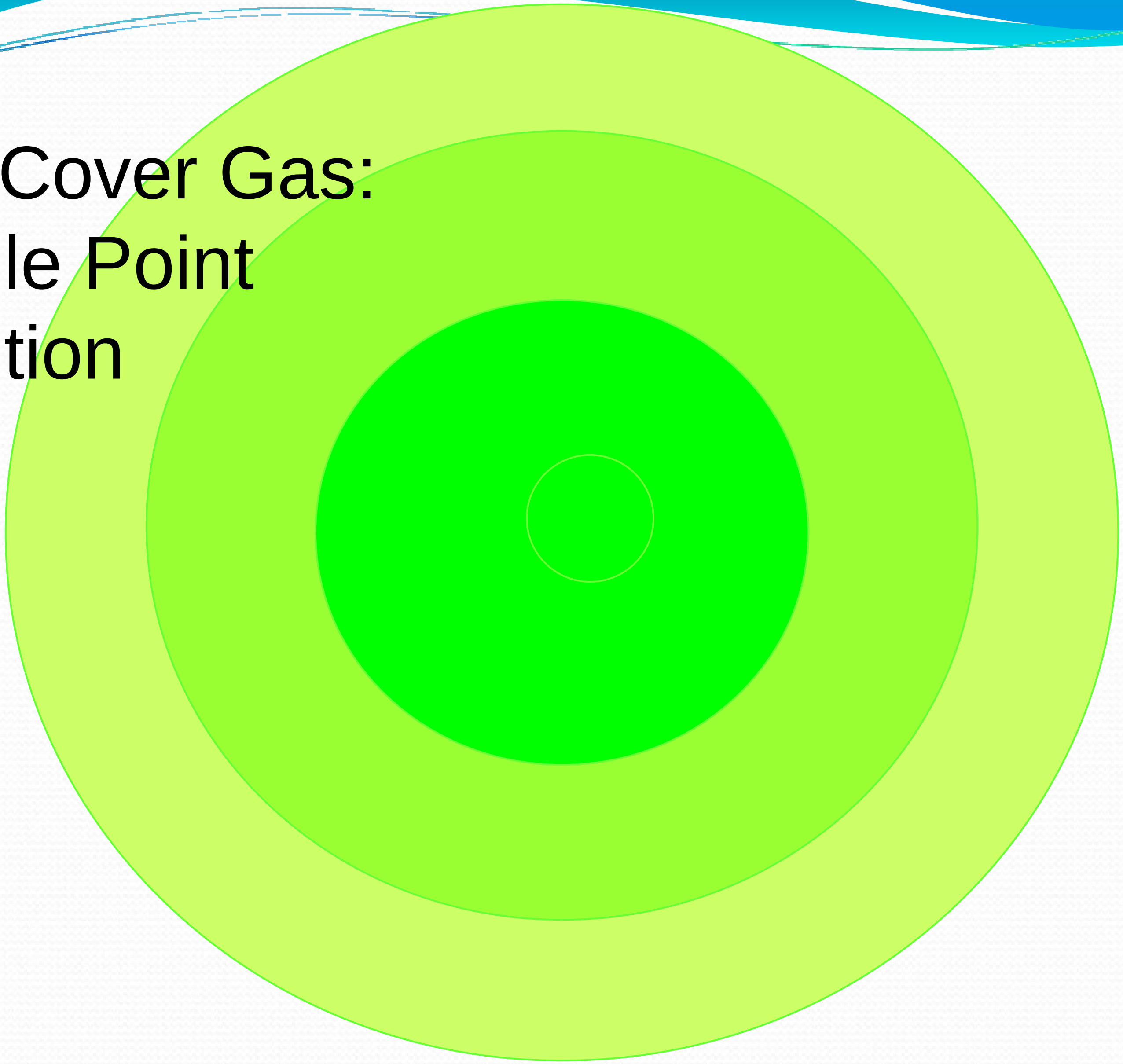
- Easier to get an even gas distribution
  - Higher flow rates make up for limited number of gas ports (almost)
  - Possibly reduced costs (Process flow control)
- Reduces the harmful effects of any HF produced

Gas Distribution

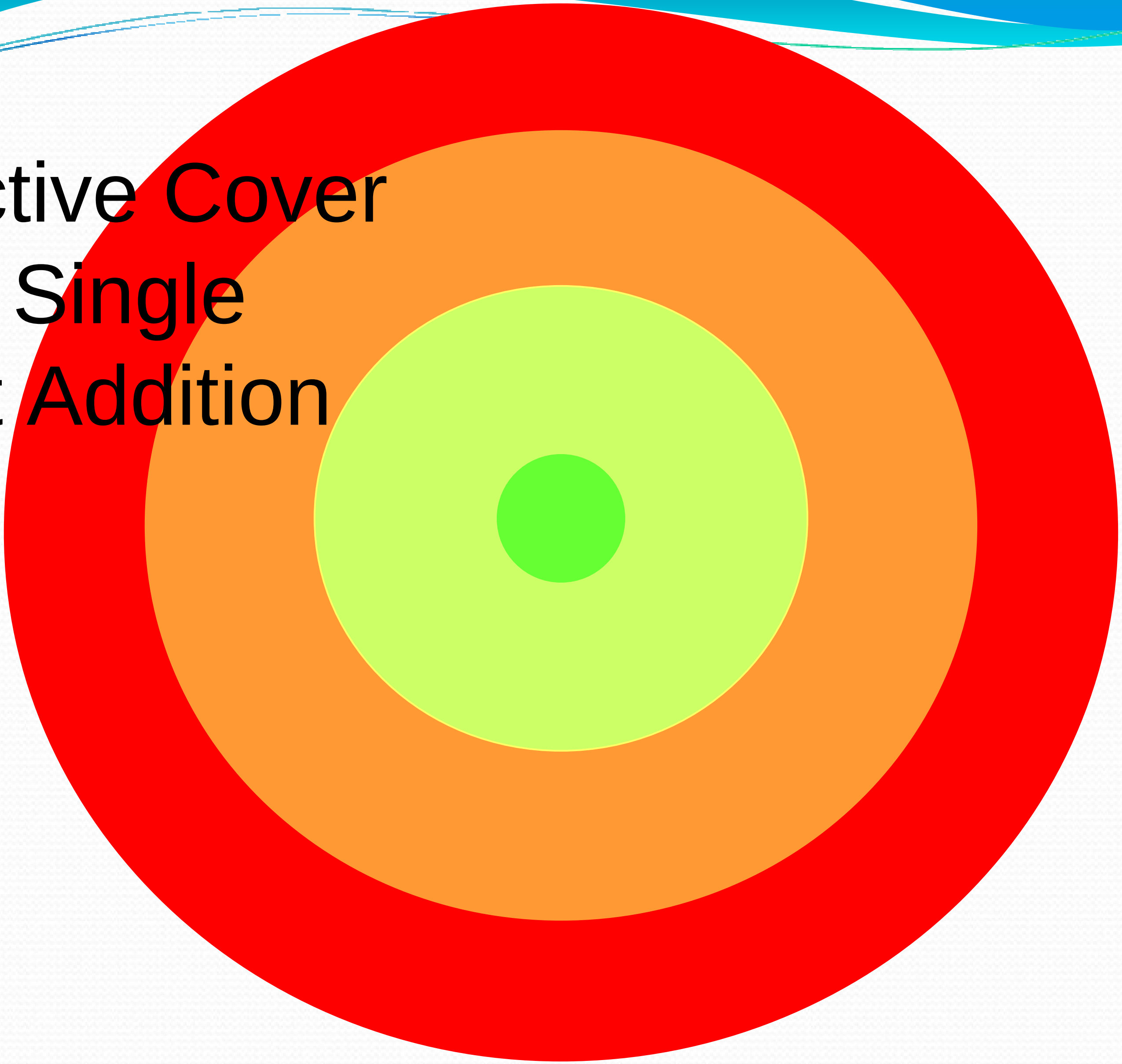
Replacement agents are more reactive

- **Cannot produce an even distribution by diffusion, limited input points, low flow rates**
- **More inlet gas ports are needed**
  - **Number is dependant upon geometry of available lid sites and flow rates**
  - **Care needed to be sure flow to each port is adequate (parallel rather than series)**

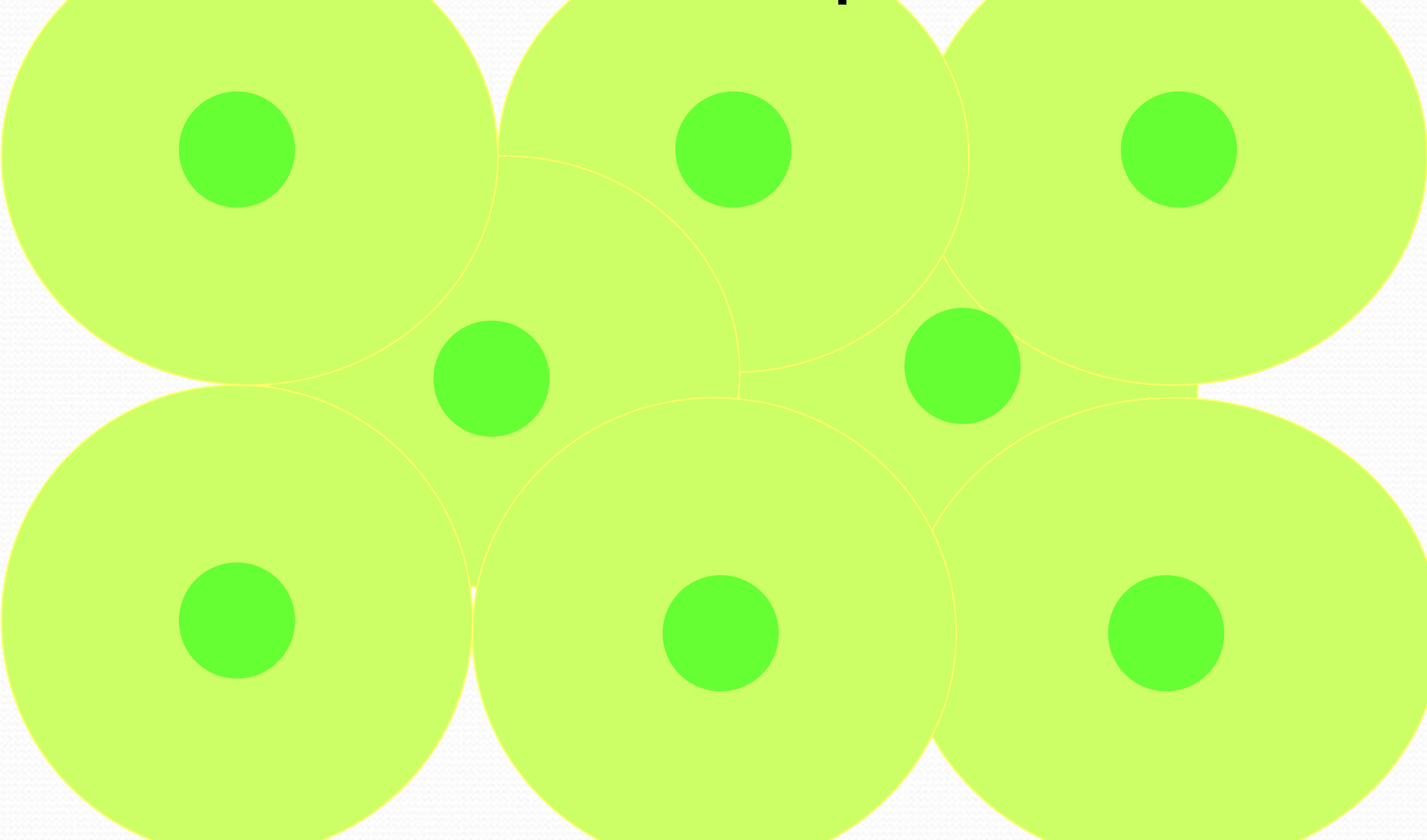
SF_6 Cover Gas: Single Point Addition



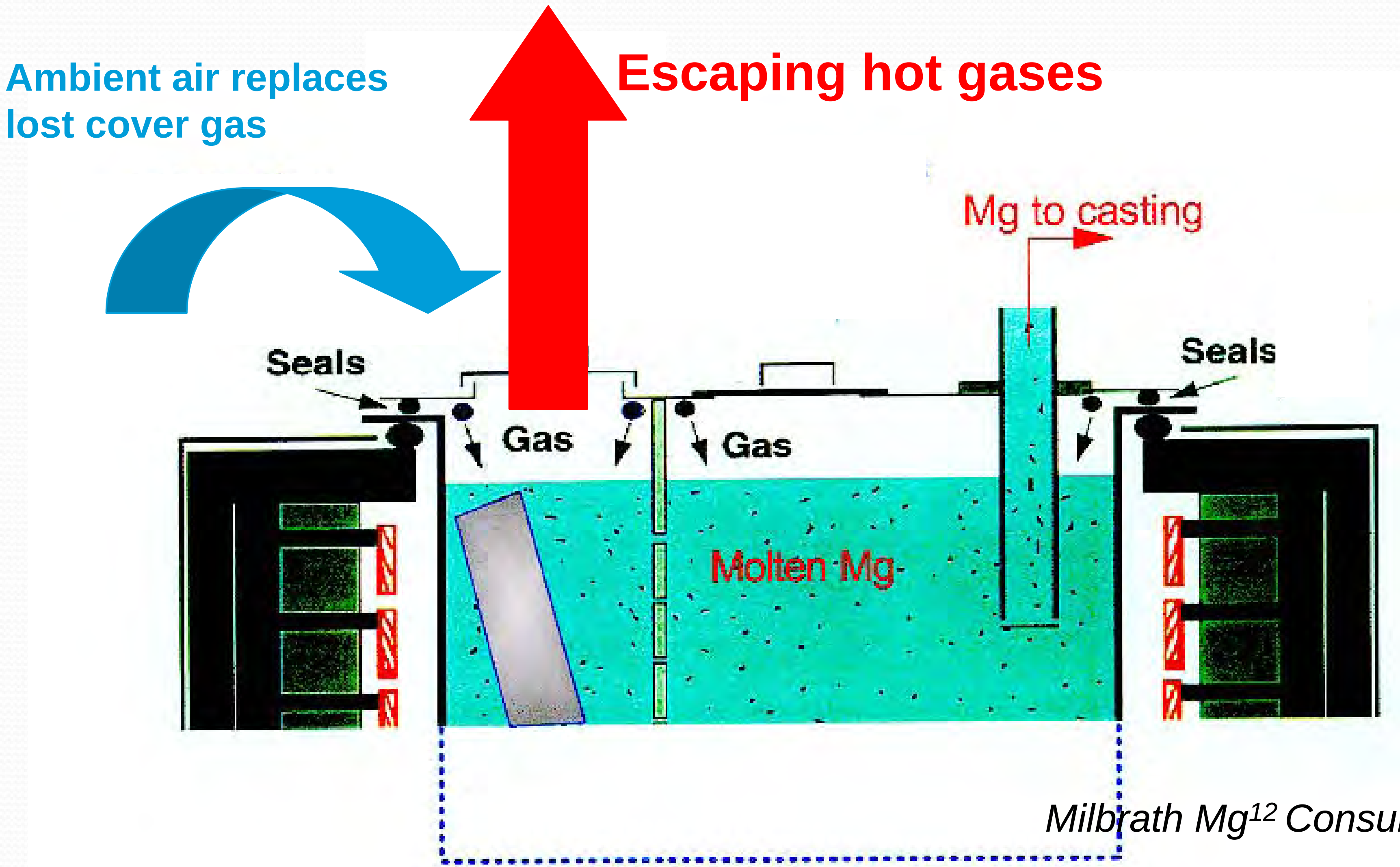
Reactive Cover Gas: Single Point Addition



Reactive Cover Gas: Multiple Point Addition



Opened Furnace Hatch



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Headspace Gases are lost Quickly

-Gas temperature 300 – 400 C

-Hot gases < ½ density of air

-Low density gas rises

English Units

Furnace Surface Area	Headspace Volume (8 inches)	Open Time	Volume Lost
(ft^2)	(ft^3)	(sec)	(ft^3)
10	6.7	1	3.14
10	6.7	5	15.7
10	6.7	15	47.1
10	6.7	60	188.4

Metric Units

Furnace Surface Area	Headspace Volume (20 cm)	Open Time	Volume Lost
(m2)	(L)	(sec)	(L)
0.93	186	1	88.7
0.93	186	5	443.6
0.93	186	15	1330.7
0.93	186	60	5322.8

Long Recovery Times

English Units

Volume Lost	Replacement time at flow rates (min)			
	20	**40**	**60**	**(ft^3/hr)**
	3.0	**6.0**	**9.0**	**(Vol Changes/hr)**
(ft^3)				
3.14	9.42	4.71	3.14	(Min)
6.7	20.1	10.05	6.7	

Metric Units

Volume Lost	Replacement time at flow rates (min)			
	10	**20**	**30**	**(L/min)**
	3.2	**6.5**	**9.7**	**(Vol Changes/hr)**
(L)				
88.7	8.9	4.4	3.0	(Min)
186.0	18.6	9.3	6.2	

Process Flow Control

Lost cover gas leads to gradual loss of control

- Minimize open time and size of opening
- Increased CGA - conc/flow rate (all the time)

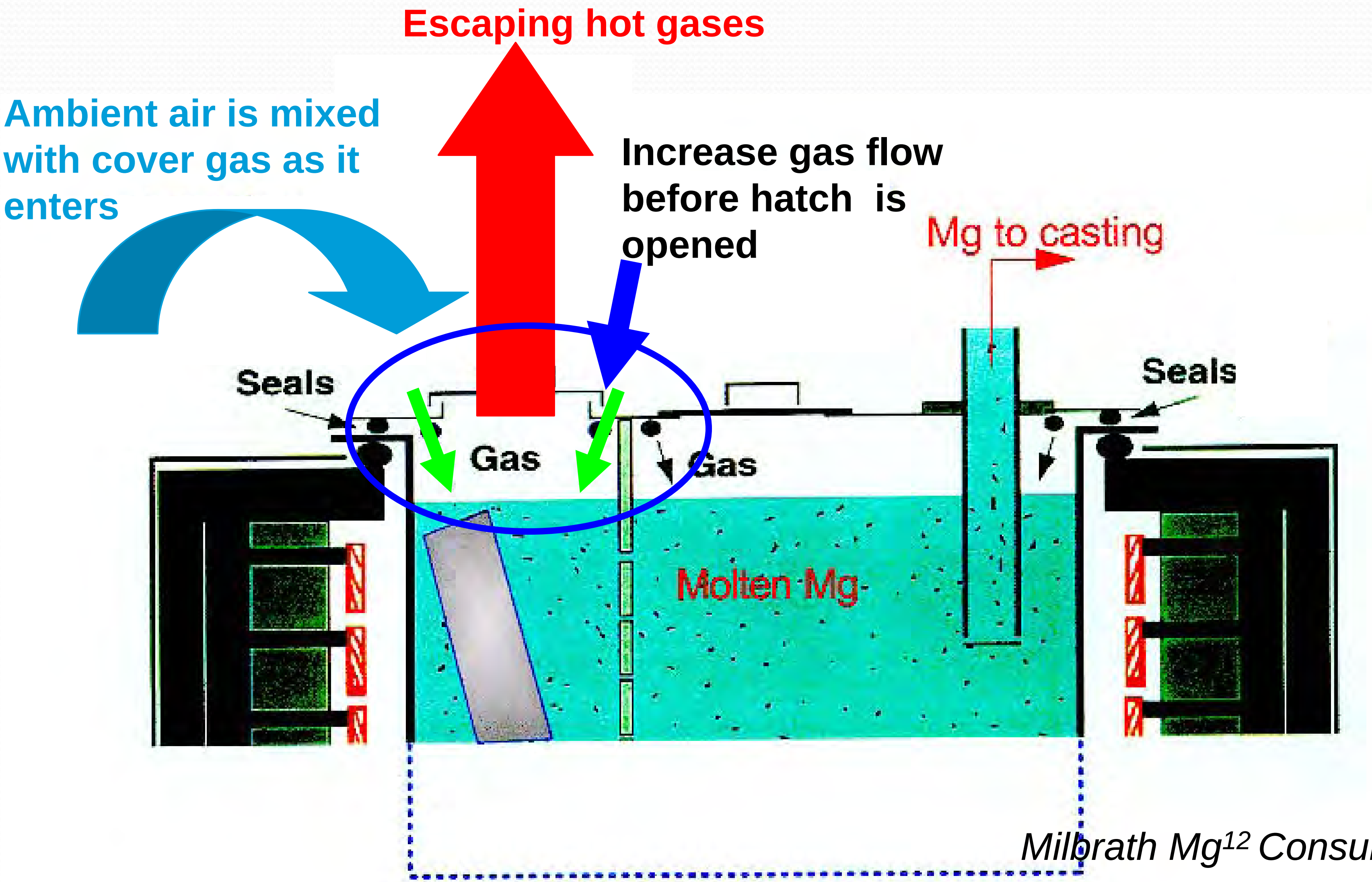
With process control:

- Increase flow rate during and after open time

  -Possible to use lower conc during closed time

  and reduce costs

Opened Furnace Hatch



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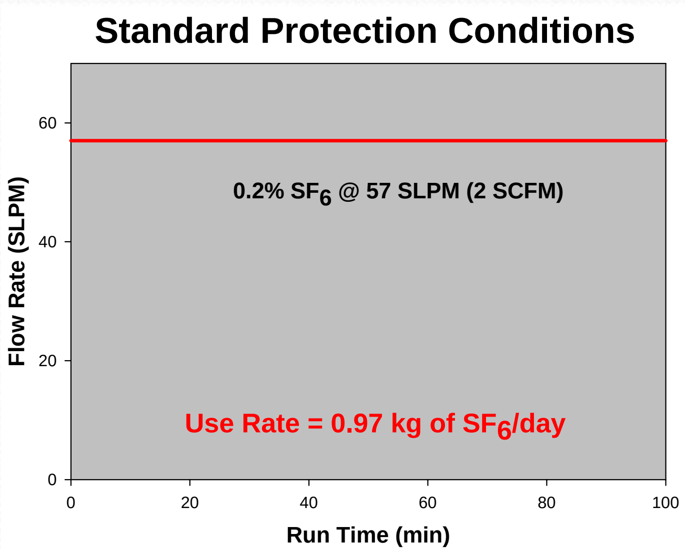

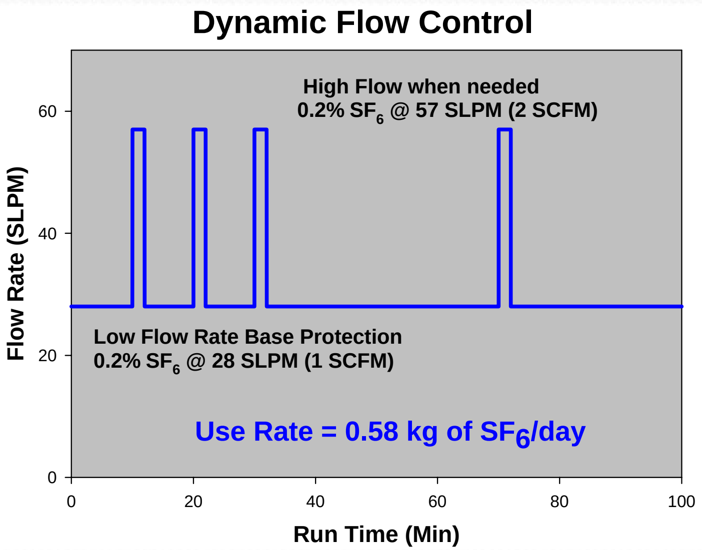

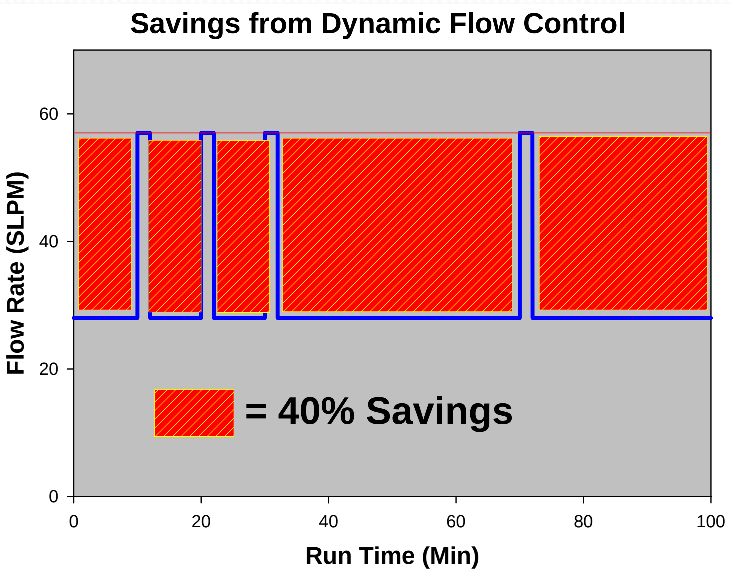

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Critical Factors for Replacements

- Carrier gas needs to have O-source and be dry
- Choice of Conc and Flow Rate are linked and can be a tool to improve gas distribution, economics
- Higher reactivity of replacements requires even distribution of cover gas
- Effects of high rates of cover gas loses can be overcome with process flow rate controls