High Volume Filling

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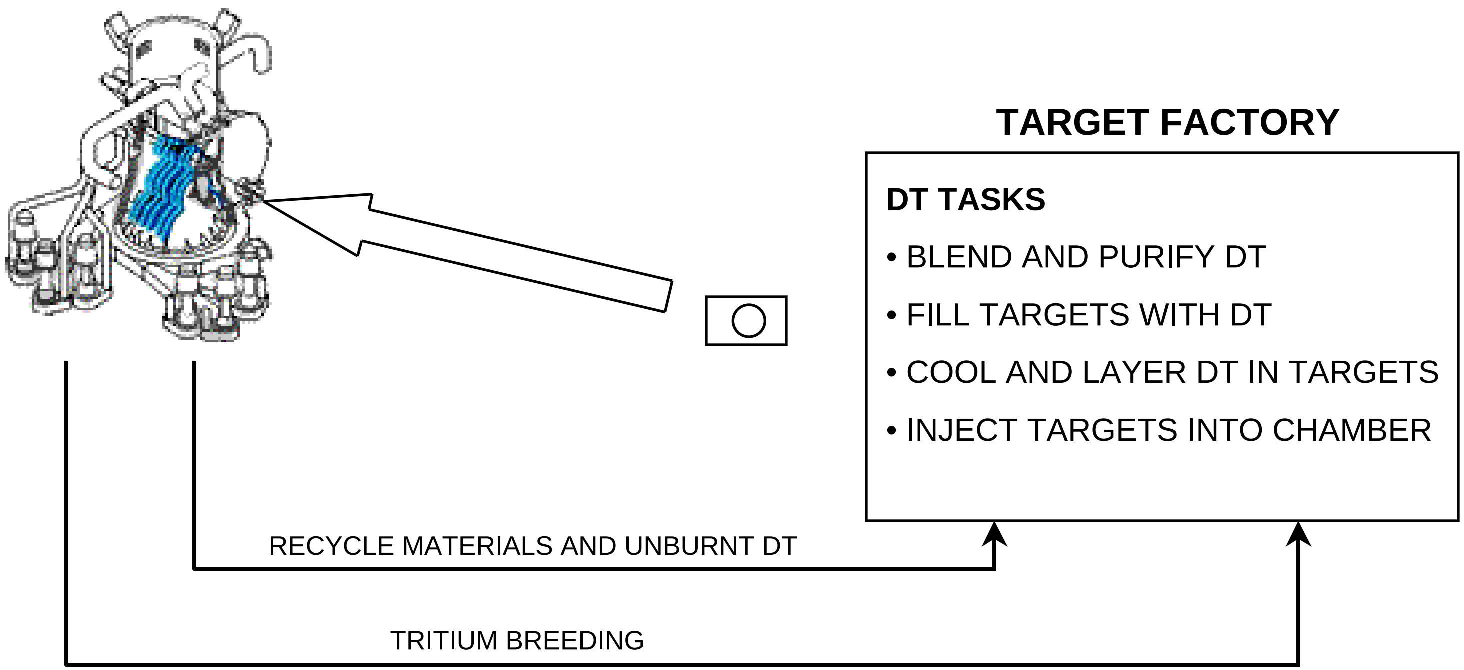
GENERAL ATOMICS

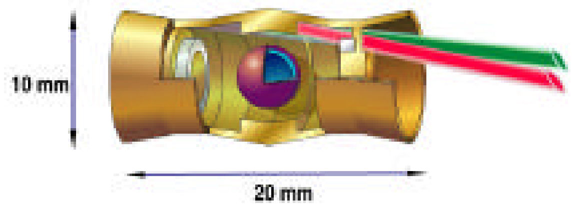
IFE plants conduct numerous tritium manipulations

- Targets used at rate of 6 to 12 Hz
- 5 to 10 x 10^5 targets/ day
- Targets typically contain ~2.5 mg of tritium
- 1.3 to 2.5 kg of tritium/day injected into reactor

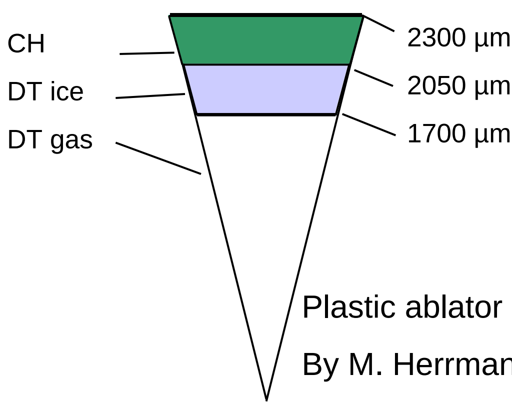


GENERAL ATOMICS

DT fuel goes into target capsule and then is layered



LLNL Close-Coupled HI Target

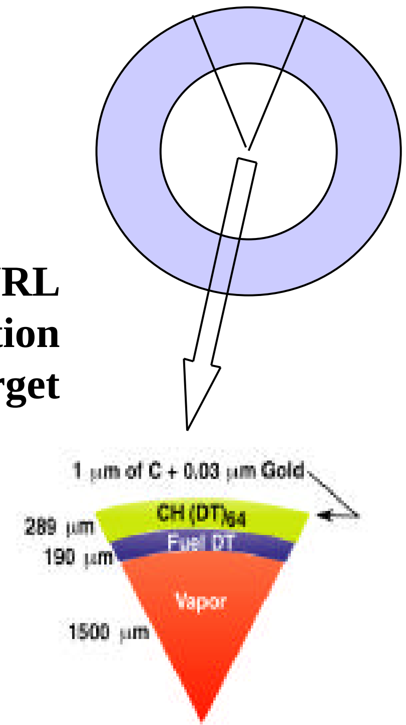


Plastic ablator capsule for HIF

By M. Herrmann, and Max Tabak

LBNL-PUB-844-01-01

NRL Radiation Preheat Target



S. Bodner, et al, Physics of Plasmas

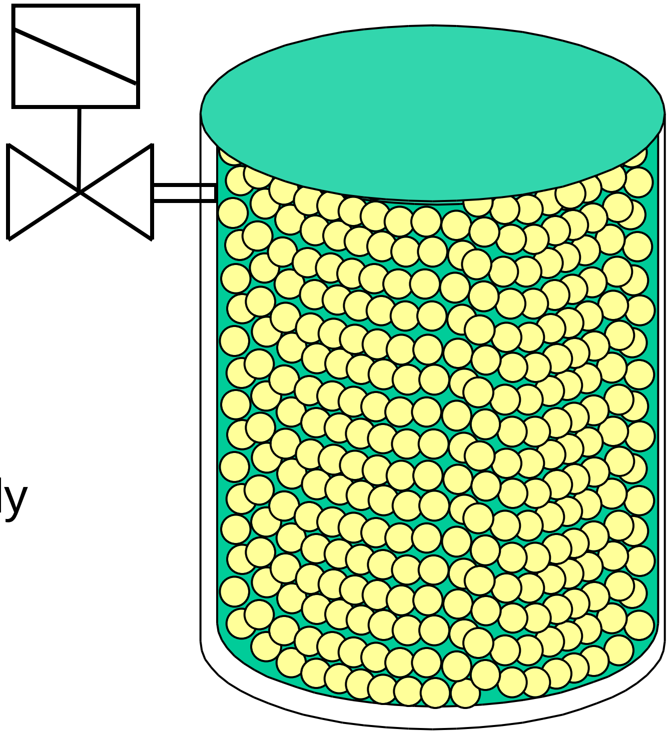
GENERAL ATOMICS

Why low-inventory methods for target filling?

- Low-inventory Filling   High Volume Filling ≡ High Throughput Filling
  - – Fast filling
- Overall purpose: Increase public safety and increase system reliability
  - – Tritium inventory reduction
  - – Provide flexibility in dealing with defective targets

Standard filling technique is permeation

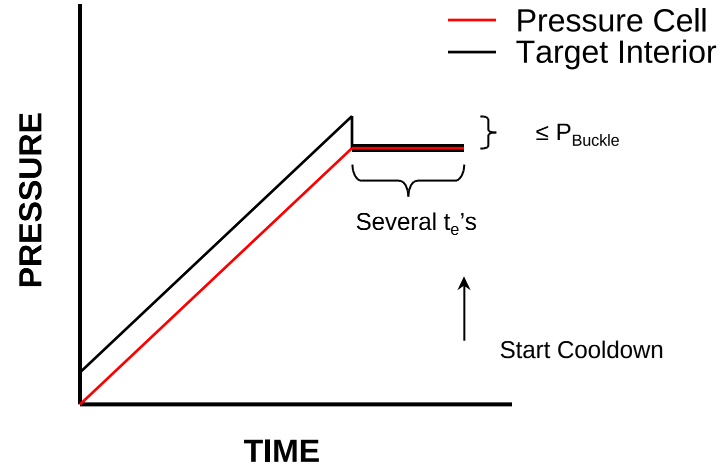
- Pluses
  - – Target shell is unperturbed
  - – Batch fill in volume mode
  - – Fuel fill density well controlled
  - – Demonstrated ICF technology
- Minuses
  - – May be slow
    - – High aspect ratio shell buckle easily
    - – High Z reflective coatings
  - – Extra DT used in inter-target space or holhraum if it is included

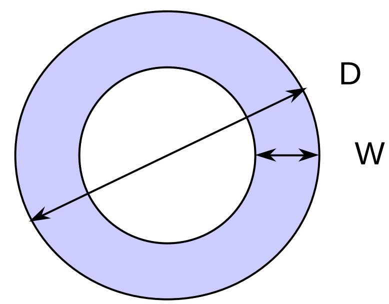


Pressure ramp fills fastest

- For thin walled capsules and ideal gas
- Fastest rate is $\frac{P_{Buckle}}{t_e}$
- $P_{Buckle} = \frac{8EW^2}{D^2\left(3\left(1-\nu^2\right)\right)^{1/2}}$
- t_e is e-folding time of permeation

$$t_e = \frac{DW}{6RTb}$$





E ≡ Elastic modulus

ν ≡ Poisson's ratio

b ≡ Permeability

R ≡ Gas constant

T ≡ Temperature

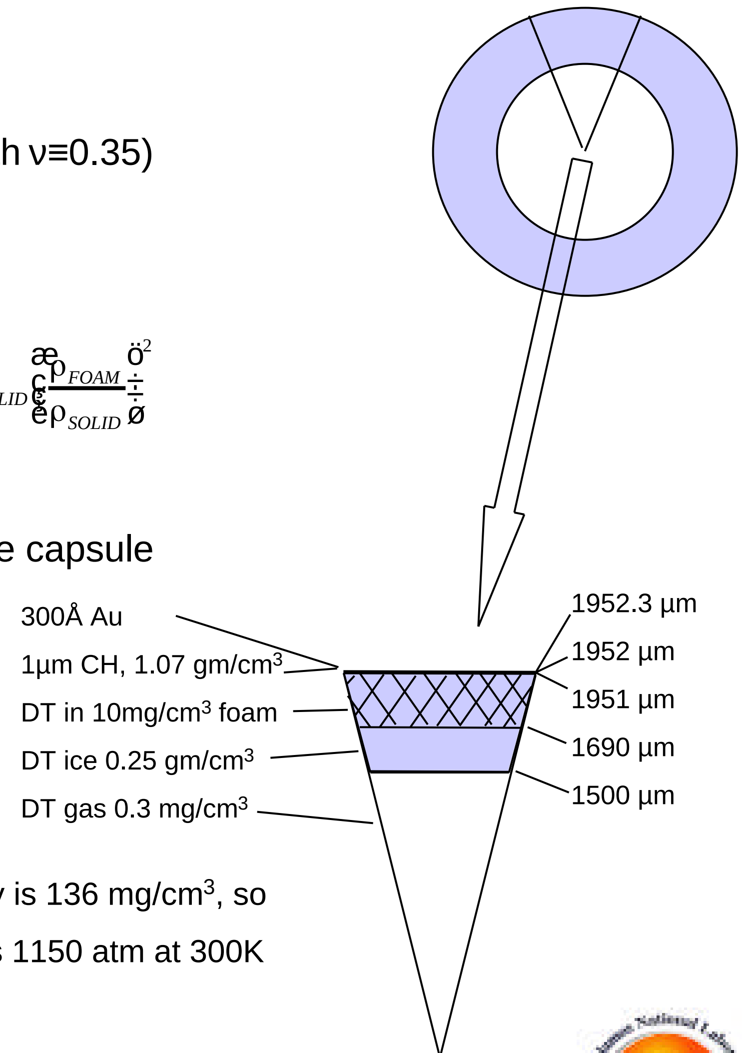
GENERAL ATOMICS

Direct drive reference scenario fills slowly

- Pre-2000 Pyrolized GDP
  - E=1.5 GPa (from data reduction of shell crush tests with ν≡0.35)
  - b=6.5 x 10^{-15} mole/(m•sec•Pa)
- Capsule alone P_{Buckle}= 0.0048 atm
- Foam alone P_{Buckle}= 0.038 atm

$$E_{FOAM} = E_{SOLID}\left(\frac{\rho_{FOAM}}{\rho_{SOLID}}\right)^2$$

- Combination P_{Buckle}= 0.047 atm
  - Foam taken to be equivalent mass solid shell just inside capsule
- t_e= 20. Sec
- $$t_{Fill} = \frac{P_{Fill}\,t_e}{P_{Buckle}} = 5.7\ day$$



DT Fill Density is 136 mg/cm³, so

Fill pressure is 1150 atm at 300K

GENERAL ATOMICS

Material improvements may significantly speed filling

DIRECT DRIVE

Capsule Data (Except Kapton)	GDP Pre-2000	GDP 2000†	GDP 2000 Exception†	Kapton HN Film	Polyimide*	Expanded Polyimide*	Polystyrene
E (GPa)	1.5	3.0	5.0	2.5	2.3 ± 0.7	1.5 ± 0.8	1.
"ν"	0.35	0.35	0.35	0.35	0.35	0.35	0.353√
ρ (gm/cm^3)	1.07	Up to 1.40		1.4			1.05
σ (MPa)	23. – 77.			231.	181. ± 23.	210->260	18. – 36
Comp.	$C_1H_{1.17}O_{0.07}$	$C_1H_{0.86}O_{0.11}$					
b (at 300K) D_2 He Ne N_2 (10^{-16} mole/(m •Pa•sec)	65. 16. 1.8	260. ? 63. 7.5	260. ?	4.4 8.2 X1/70 of He	9.0 ± 1.7 10.5 ± 1.9	2700. ? X300 §	60.
P_{Buckle} (atm)	0.047	0.067	0.11	0.055	0.051	0.033	0.032
t_e (sec)	20.	5.0 ?	5.0 ?	300.	140.	0.48 ?	22.
t_{Fill} D_2 (day)	5.7	1.0 ?	0.60 ?	71.	38.	0.19 ?	9.

† GA: ICF Target Support Contractor, FY00 Year End Review, 13th TFM Proceedings, pg 637

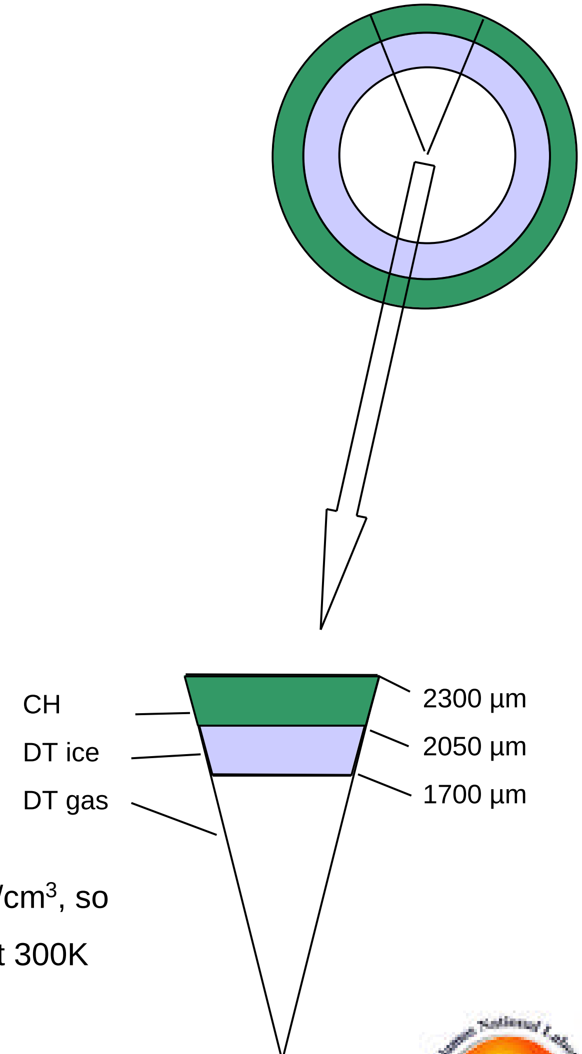
* UR/LLE: 13th TFM Proceeding, pg 623

§ 50% showed no change, 10% show 300 X's, 40% had permeability too large to measure

GENERAL ATOMICS

Indirect drive reference fills relatively quickly

- Pre-2000 Pyrolized GDP
  - E=1.5 GPa (from data reduction of shell crush tests with ν≡0.35)
  - b=6.5 x 10^{-15} mole/(m•sec•Pa)
- Capsule P_{Buckle}= 220 atm
- t_e= 5300. sec
- $$t_{Fill} = \frac{P_{Fill} t_e}{P_{Buckle}} = 5.3 \ hour$$
- $t_{fill} + 2t_e$ = 8.2 hour



DT Fill Density is 107 mg/cm^3, so

Fill pressure is 777 atm at 300K

Material improvements may significantly speed filling

INDIRECT DRIVE

Capsule Data (Except Kapton)	GDP Pre-2000	GDP 2000†	GDP 2000 Exception†	Kapton HN Film	Polyimide*	Expanded Polyimide*	Polystyrene
E (GPa)	1.5	3.0	5.0	2.5	2.3 ± 0.7	1.5 ± 0.8	1.
"ν"	0.35	0.35	0.35	0.35	0.35	0.35	0.353√
b (at 300K) D_2	65.	260. ?	260. ?	4.4	9.0 ± 1.7	2700. ?	60.
He				8.2	10.5 ± 1.9		
Ne	16.	63.					
N_2	1.8	7.5		X1/70 of He		X300 §	
(10^{-16} mole/(m•Pa•sec)							
P_{Buckle} (atm)	220	430	720	360	330	220	140
t_e (sec)	5300	1300 ?	1300 ?	78,000	38,000	130	5700
t_{Fill} D_2 (hour)	5.3	0.66 ?	0.40 ?	47	25	0.13 ?	8.6
$t_{Fill} + 2t_e$(hour)	8.2	1.4 ?	1.1 ?	90.	42	0.20 ?	12

† GA: ICF Target Support Contractor, FY00 Year End Review, 13th TFM Proceedings, pg 637

* UR/LLE: 13th TFM Proceeding, pg 623

§ 50% showed no change, 10% show 300 X's, 40% had permeability too large to measure

GENERAL ATOMICS

Increasing temperature can also reduce filling time

- Polystyrene $$b(T) = 1.0 \times 10^{-12} e^{\frac{-1535\,K}{T}} \, mole/(m\ \ Pa\ \ \mathrm{sec})$$ for D_2

- GDP (deuterated) $$b(T) = 3.2 \times 10^{-13} e^{\frac{-1464\,K}{T}} \, mole/(m\ \ Pa\ \ \mathrm{sec})$$ for He

- Same fill density requires higher pressures at higher temperatures

$$P = \rho Z R T$$

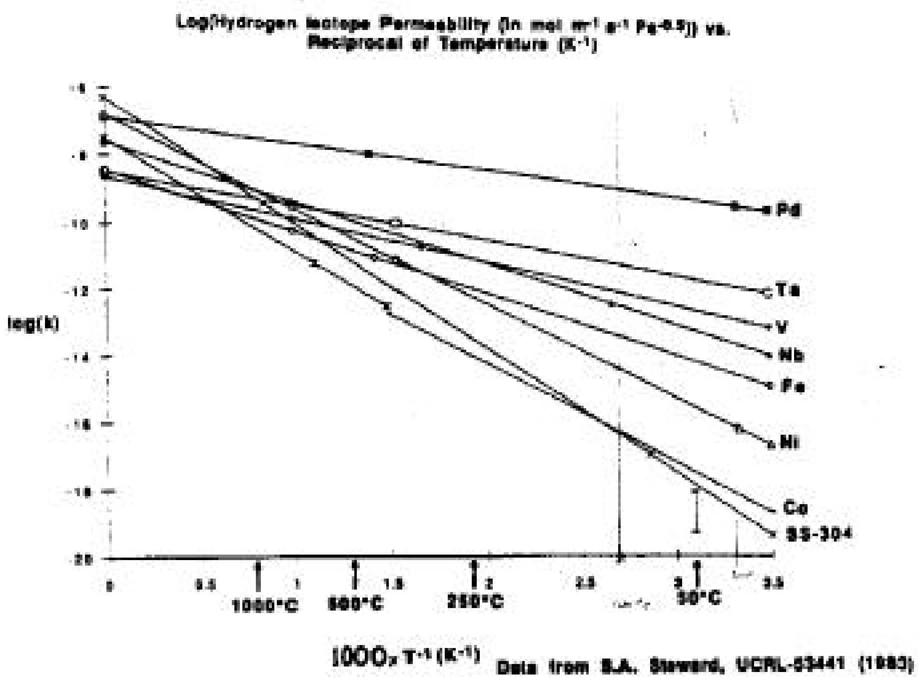
- 100 °C can shorten fill time by

$$\left(\frac{e^{\frac{-1464\,K}{300\,K}}}{e^{\frac{-1464\,K}{373\,K}}} \right) \left(\frac{373\,K}{300\,K} \right) \left(\frac{\sim 1.58}{\sim 1.77} \right) = \sim 0.4$$

Permeability Temperature Compressibility

What about that pesky high Z overcoat on some DD targets?

- It's a rate problem
  - Need $Overcoat\ t_e < Capsule\ t_e$
- Only 300 Å thick (nominally of Gold)
- Pd, Ta, V, Nb have high bulk permeabilities



Using bulk properties few metal coatings have fill times short compared to polymer capsule

TIME TO FILL METAL SHELL OVERCOAT SHELL

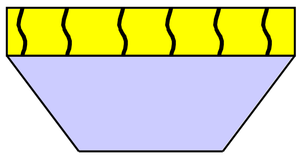
T (K)	Pd	Ta	V	Nb
300	4.4 hr	50 day	1.3 yr	6.6 yr
373	1.4 hr	10 day	60 day	0.44 yr

Shell Radius 1952 µm, Metal 300 angstrom thick, Overpressure maintained at 0.047 atm (consistent with backing by highly permeable polymer shell 1µm thick), Final pressure at 300 K is 1150 atm

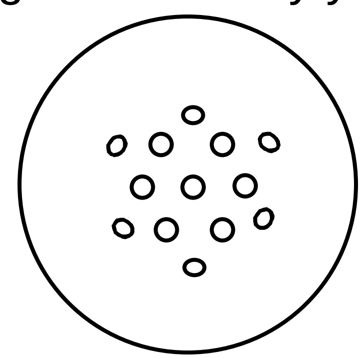
- Only Palladium has a fill short compared polymer capsule
- Tantalum could be considered on a thicker (4 µm) capsule
- Additionally overcoats need
  - To work for target design
  - Low emissivity (Pd fails here)
  - Meet radioactivity/waste criteria
  - Control of hydride or oxide effects, if any

The thin film permeability needs to be investigated

- Thin film effects can increase rate of DT passage through films
  - Deposit Gold with columnar structure
  - Pin holes
  - Grain boundaries
  - Cracks

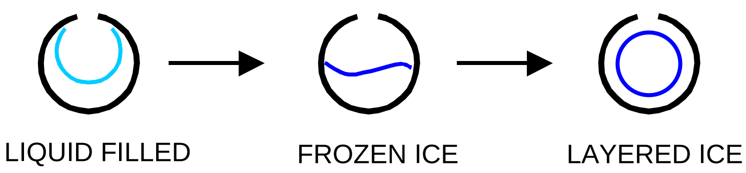


- An HCP array of pinholes separated by 0.5 µm, with 0.1% of target's area implies a pinhole diameter of 170Å
  - Target Volume/Array's Short pipe molecular conductance gives Overcoat t_e=4msec
  - Hexagonal mud-crack array with 0.1% target's area may yield much longer t_e

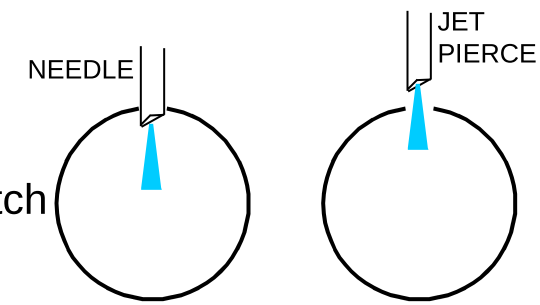


Can targets be filled through a small hole?

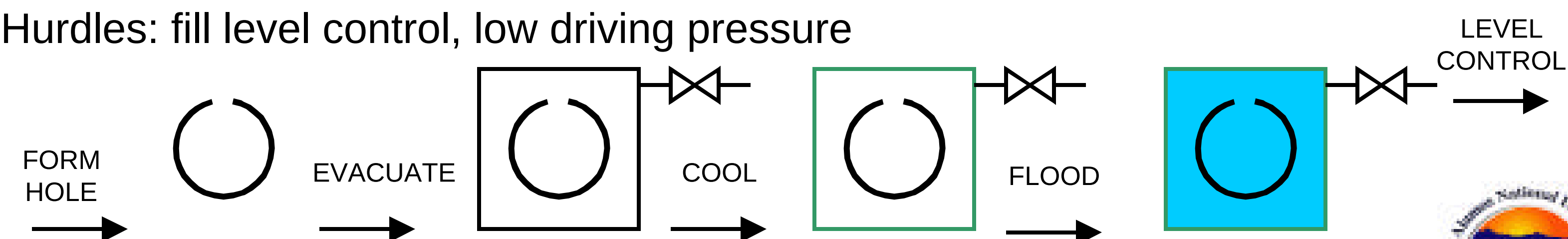
- Hole must be small. Is ≤0.5μm in diameter small enough?
- How can it be layered without leaking?
  - Plug hole?
  - Keep hole at top until solid or layered?



- How fast can it be filled through a hole?
  - Pierce and inject
    - Bonus: high driving pressure, some fill level control
    - Hurdles: mechanical damage target and needle, Area batch

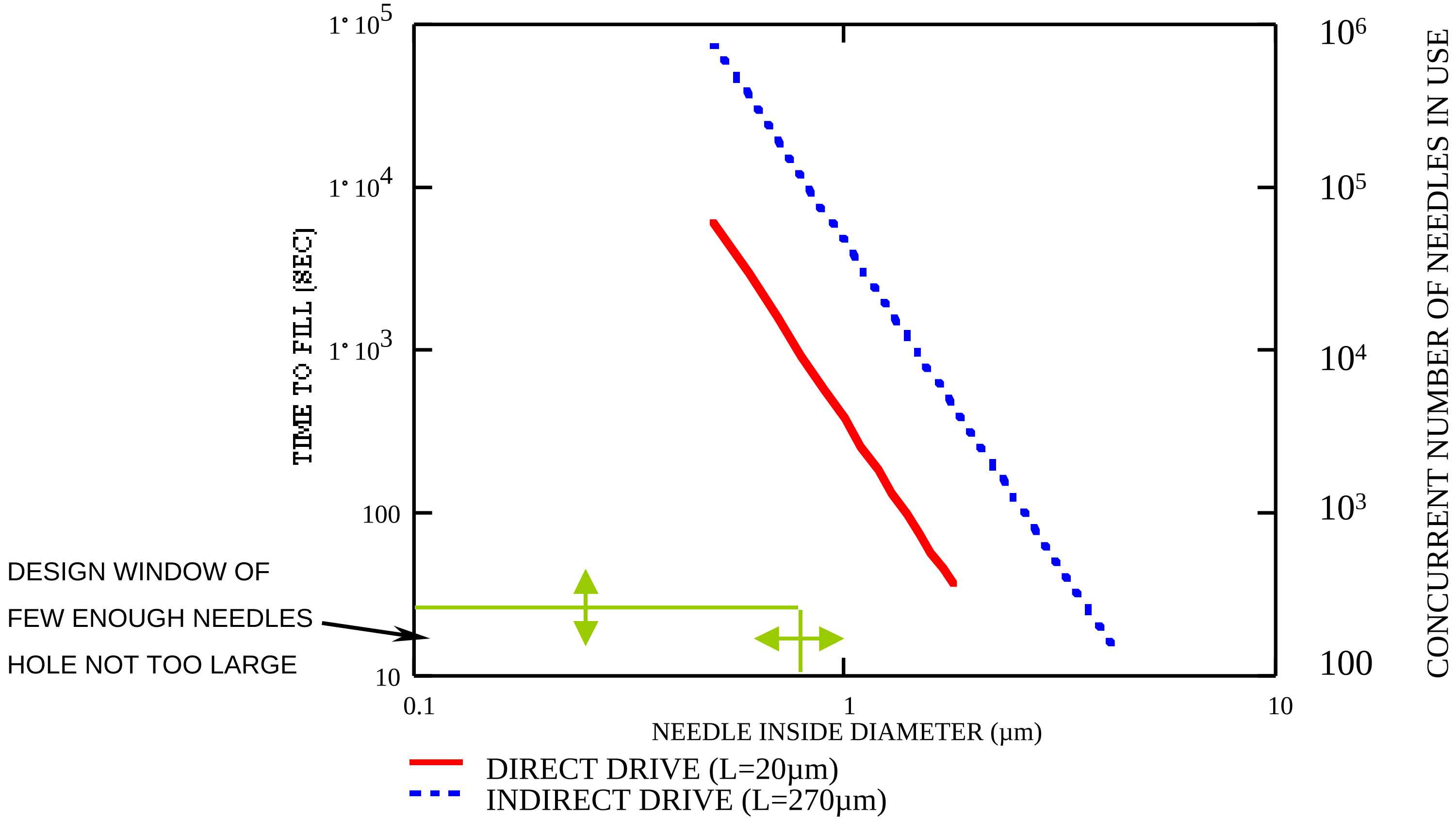


  - Flooding
    - Bonus: hole drilling at room temperature, no needle, volume batch
    - Hurdles: fill level control, low driving pressure



Is needle filling slow enough to require hole plugging?

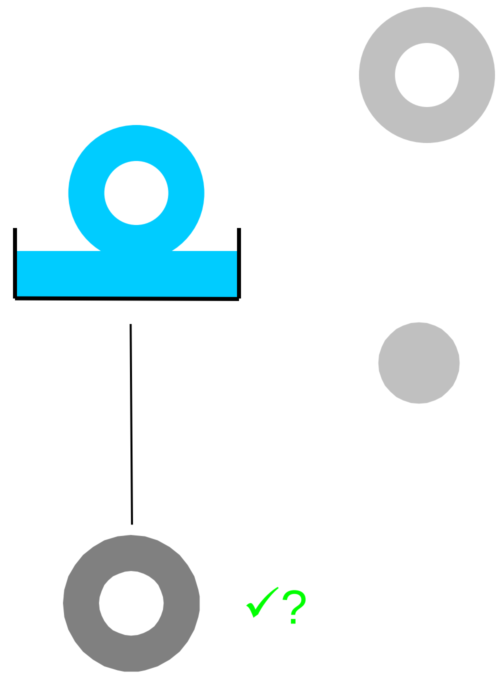
- Laminar flow calculation with DT saturated fluid properties at 22K and driving pressure difference at 1.7 MPa (just below critical pressure)



GENERAL ATOMICS

Would an all foam capsule be easier to fill?

- Start with unsealed foam shell
- Fill by dip and wick
- Freeze and Layer DT
  - Solid DT protects foam from acceleration forces
- Inject
  - Reactor black body radiation melts DT, then evaporates exterior DT
  - DT vapor keeps exterior of foam cool (no foam melting)



- Lots of obstacles to work out
  - Over filling to get pure DT layer inside
  - Avoiding DT loss from outer surface
  - Process control for uniform fill and loss
  - For indirect drive, need last second cryogenic hohlraum assembly

Summary

- Permeation filling appears workable for:

  (but optimization or faster method would be helpful)

  – Polymer capsule indirect drive targets

  – Non metal overcoated direct drive targets

- Permeation rate for thin film metal overcoats needs investigation for direct drive

- Liquid injection filling through micro-needles will:

  – Require hole plugging for indirect drive

  – Probably require hole plugging for direct drive

- Liquid flooding filling will:

  – Require hole plugging for indirect drive (TBD for direct drive)

  –Need work on ideas to control filling level

GENERAL ATOMICS

Info

- The mean free path for DT at 300 K is
  - 1900 Å at 1 atm
  - 3Å at 1150 atm