IMPACT OF INCLINED RING

C.H. Rode
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INTRODUCTION

The SSC reference design specified a level ring, and therefore the cryogenic designs were optimized for this. In addition there was a major effort to standarize the refrigeration designs; even though people always concentrate on the differences, this was highly successful.

In the real world the optimum cryogenic design will be a strong function of the following.

1. Requirements for magnet changes.
2. The maximum temperature permitted in the magnet coils (300-330K).
3. One or two rings of magnets.
4. Iron or no-iron.
5. Incline of ring.
6. Day-night power pricing.

These are not independent problems; for example the question of whether one uses U-tubes, valves or purges for isolation is affected by items 1,2,3,4 & 5. Another example is that: while I firmly believe in the use of liquid nitrogen, having only one ring sufficiently complicates nitrogen transport during commission and magnet repair, that I wouldn't use it unless there is a tremendous day/night pricing advantage. A third example is that: we have ruled out 2Ø helium counterflow for Design "D" because of the complication in the piping for cold iron magnet changes.

EFFECT OF INCLINE ON 2Ø He

While currently no one is planning to use 2Ø helium for magnet cooling, one will have to deal with it in off design conditions. Two examples are: 1) During quench recovery designs B & C have 2Ø in their 10° shield pipes, and 2) For a relief valve replacement there will be 2Ø helium in the magnet coils.

Supercritical helium also acts similar to 2Ø helium near the critical point. (2.4 atm 5.2 to 5.4K provides a factor of 2.1 in density).

Figure 1 shows the original Design "B" operating load lines superimposed on the Baker Diagram. The boundries between flow regions are not certain. We do not know that these boundries are correct for helium and what the effect of inclines are.

The BR 2Ø test set up will determine these flow boundries as a function of inclines up to 2%. The stratified flow regions is always a disaster from a controlability standpoint, since one can have tremendous inventory and flow rate oscillations. In addition one can have liquid flowing in one direction and gas in the other.

Slug and plug flow, while they often break pipes in water and nitrogen system, may be ok for helium because of the low liquid/gas density ratio.

EFFECT OF INCLINE ON 1Ø He

Currently all designs are using a 1Ø system with dewars. This configuration is totally stable for any incline; there are only minor temperature and pressure effects. For Design "B" with a 1/2% grade we get a 1Ø pressure differential of 7.5 psid and a .07K temperature differential due to the pressure differential in the gas header (Table I).

EFFECT OF INCLINE ON He SHIELD

Since the reference design report all designs have been modified so that only pure gas is used to cool the helium shield. Therefore all the designs are stable accept possibly after quenches. For Design "B" with a 1/2% grade we get a pressure differential of 0.5 psid.

EFFECT OF INCLINE ON NITROGEN SHIELD

During the steady state we have a significent pressure differential; for Design "B" with a 1/2% grade we get a 45 psid pressure differential.

The inclined rings present serious problems during cooldown. Small scale lab tests indicate that grades as little as 0.1% cause 1/8" liquid drops to run down the pipe with a velocity of 1.0 ft/sec; larger drops run faster. The BR 2Ø test set up will look for shock waves in a 100 ft. line as well as liquid velocities. The line may be too short to see shock waves; in the Tevatron Transfer Line we see pressure doubling shock waves (35 to 70 psig). Old experiments on small diameters level lines have given shock waves of several hundred psi.

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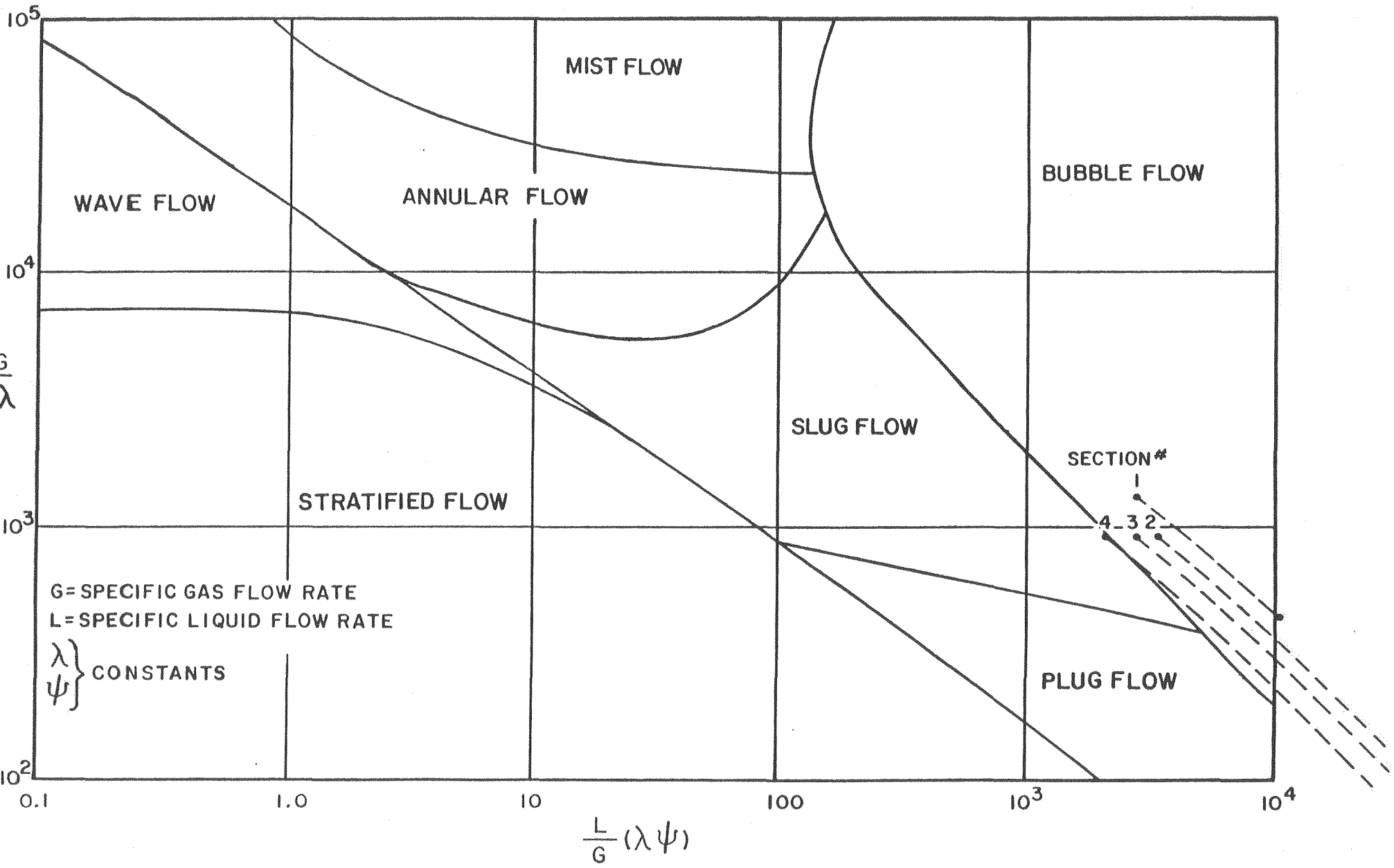
MIST FLOW
WAVE FLOW
ANNULAR FLOW
BUBBLE FLOW
SLUG FLOW
STRATIFIED FLOW
PLUG FLOW
SECTION #
1
4 3 2
G = SPECIFIC GAS FLOW RATE
L = SPECIFIC LIQUID FLOW RATE
λ
ψ
CONSTANTS
10^5
10^4
10^3
10^2
$\frac{G}{\lambda}$
0.1
1.0
10
100
10^3
10^4
$\frac{L}{G}(\lambda\psi)$

EFFECT OF GRADE ON DESIGN B

% GRADE FOR 28,000 ft.	2Ø HELIUM SYS. Stable	ΔP psid	ΔT K	1Ø HELIUM SYS. Stable	ΔP psid	ΔT K	HELIUM SHIELD Stable	ΔP psid	NITROGEN SHIELD Stable	ΔP psid
.0/0 FT	* OK (needs to be confirmed)	0	0	OK	0	0	OK	0	OK	0
.1/28 ft	* OK?	>.2 <1.5	>.014 <.1	OK	1.5	.014	OK	.1	* Possible cooldown shock waves ?	9
.2/56 ft	* OK?	>.4 <3.0	>.028 <.2	OK	3.0	.028	OK	.2	* Possible cooldown shock waves ?	18
.3/84 ft	* Possible unstable	>.6 <4.5	>.042 <.3	OK	4.5	.042	OK	.3	* Probable cooldown shock waves ?	27
.4/112 ft	* Possible unstable 84 Booster pumps			OK	6.0	.056	OK	.4	* Probable cooldown shock waves ?	36
.5/140	* Possible unstable 84 Booster pumps			OK	7.5	.070	OK	.5	* Cooldown shock waves	45
Saddle 8% for 3500 ft 280 ft	Not usable	(in this region one would use 1Ø system)		OK	15.	.14	OK	1.0	* Requires special hardware for cooldown	90

* BR 2Ø Experiment to provide data

TABLE I

The impact of shock wave will require some combinations of the following options.

1. Don't use liquid nitrogen in the magnets.
2. Have mobile vaporizers such that only gasseous nitrogen is used during cooldowns. There will still be a major problem of how to switch from cold gas to subcooled liquid in operate mode.
3. Have vent stacks at every isolation box (rather than every other) so that all cooldowns can be done uphill.
4. Have a small low pressure nitrogen header so that all cooldowns can be done uphill.
5. For the saddle option we may want a separate nitrogen transfer line in the saddle region especially if the nitrogen plants are at the interaction regions.

SAFETY IMPLICATIONS

Liquid nitrogen spilled on the floor will roll down the tunnel at ~1.0 ft/sec with a 0.1% grade. It therefore becomes critical that the floor be sloped toward the drains in order to reduce the surface area of the spill.

We believe that helium with a few tenths of a percent grade will be pushed along the ceiling by the 3 mph circulating air. We also believe that in the saddle configuration, 8% grade, helium will move uphill independent of circulating air. These two beliefs need to be confirmed and the velocity measured for the saddle configuration.

CONCLUSIONS

1. An inclined ring does not present a major problem for the refrigeration system.
2. The saddle also is not a major problem.
3. The cost impact is probably less than $10M for a few hundred feet of full ring tilt.
4. The "BR refrigerator" 2Ø test program, which we we seriously considered dropping, should be expanded to include nitrogen.

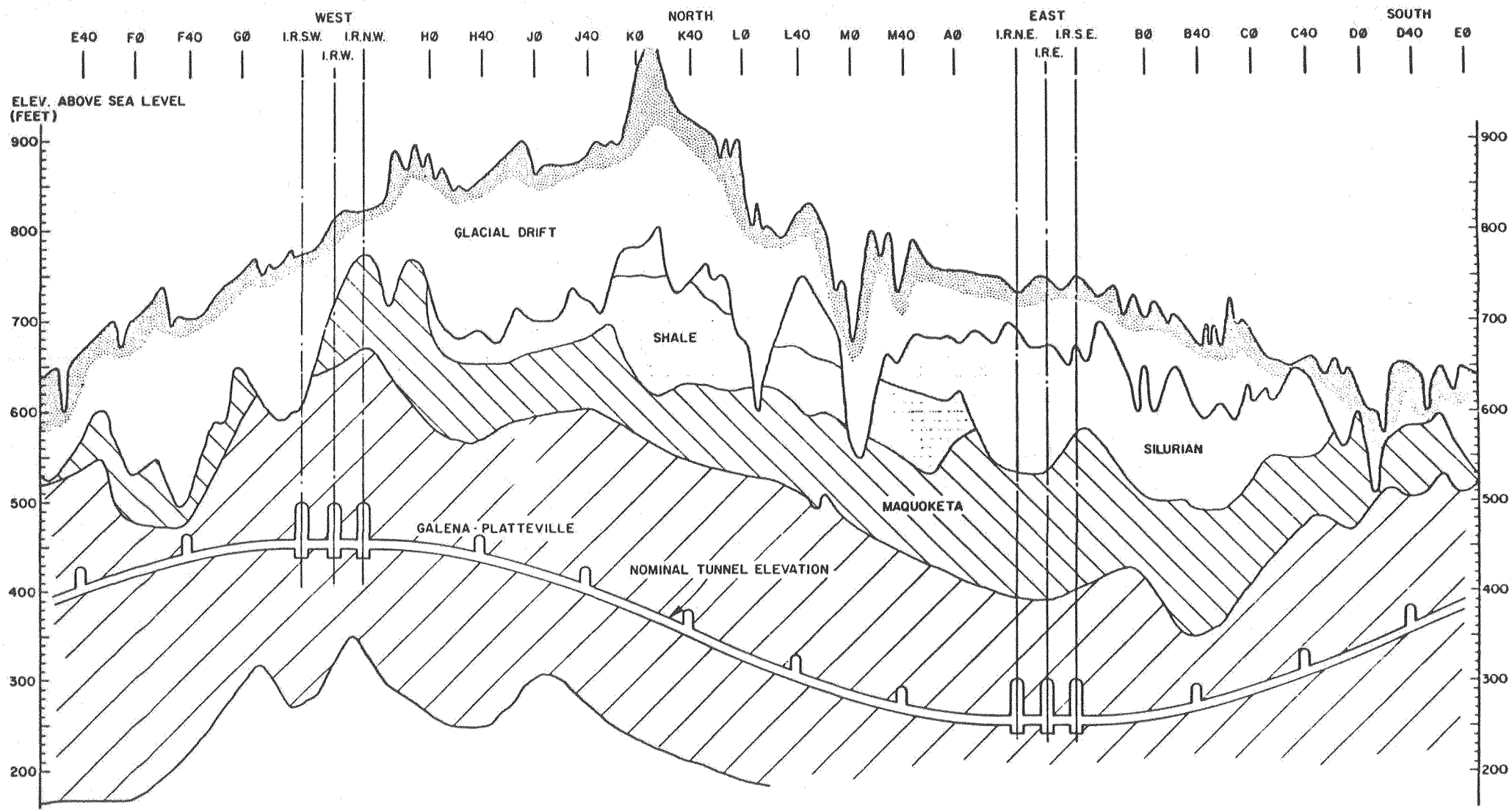

FIG. 2 INCLINED TUNNEL - 200 FT. DIFFERENTIAL (~0.2%)