SNO-STR-91-11

Bladder with dissolved substances for NC

R.B. Schubank, UBC

The format of this presentation will be to address questions posed by H. Robertson regarding NC detection schemes.

<u>Question A:</u> *What is it?*

It is proposed to insert a transparent, flexible, thin, impermeable bladder into the main acrylic vessel to physically sub-divide to it into two regions:

- an inner one containing an (n,γ) dissolved salt (NaCl, or Gd, or Cd)
- an outer one containing an (n,α) dissolved salt (H_3BO_3)

Nominal size and shape of the bladder is 5m radius <u>sphere</u>, with a cylindrical neck 8m long by 24" diameter, although other sizes & shapes (hemi-sphere) are also feasible. The bladder can be inserted or removed at anytime.

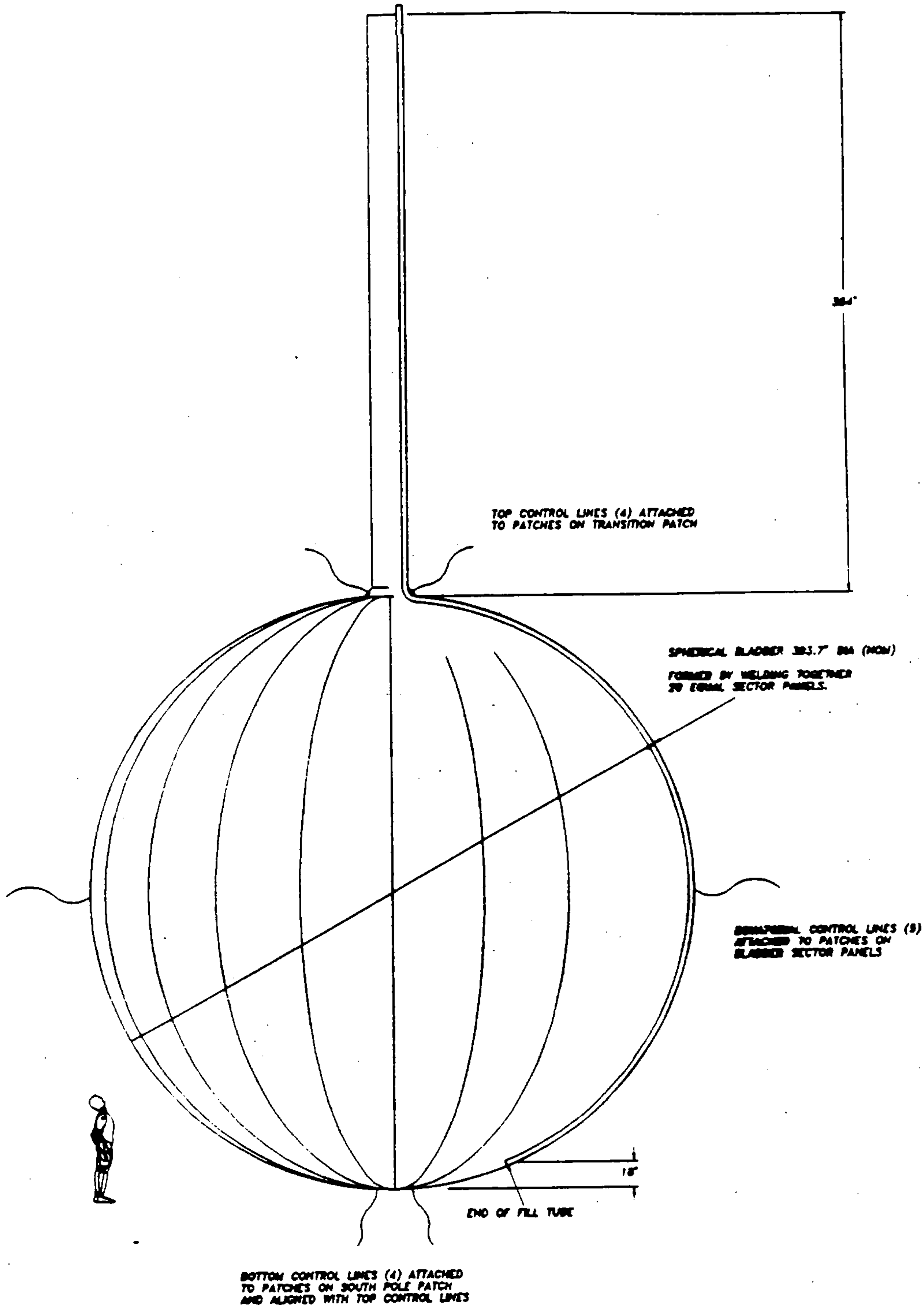
Desired material (so far) is 1-5mil TEFLON film (see spec sheet), chosen for its mechanical, physical, chemical and optical properties (refractive index matches water!)

Other materials (TEDLAR, ACLAR, SARAN, etc.) are superior in some aspects, such as ion-permeability or weldability; a compromise may still need to be reached.

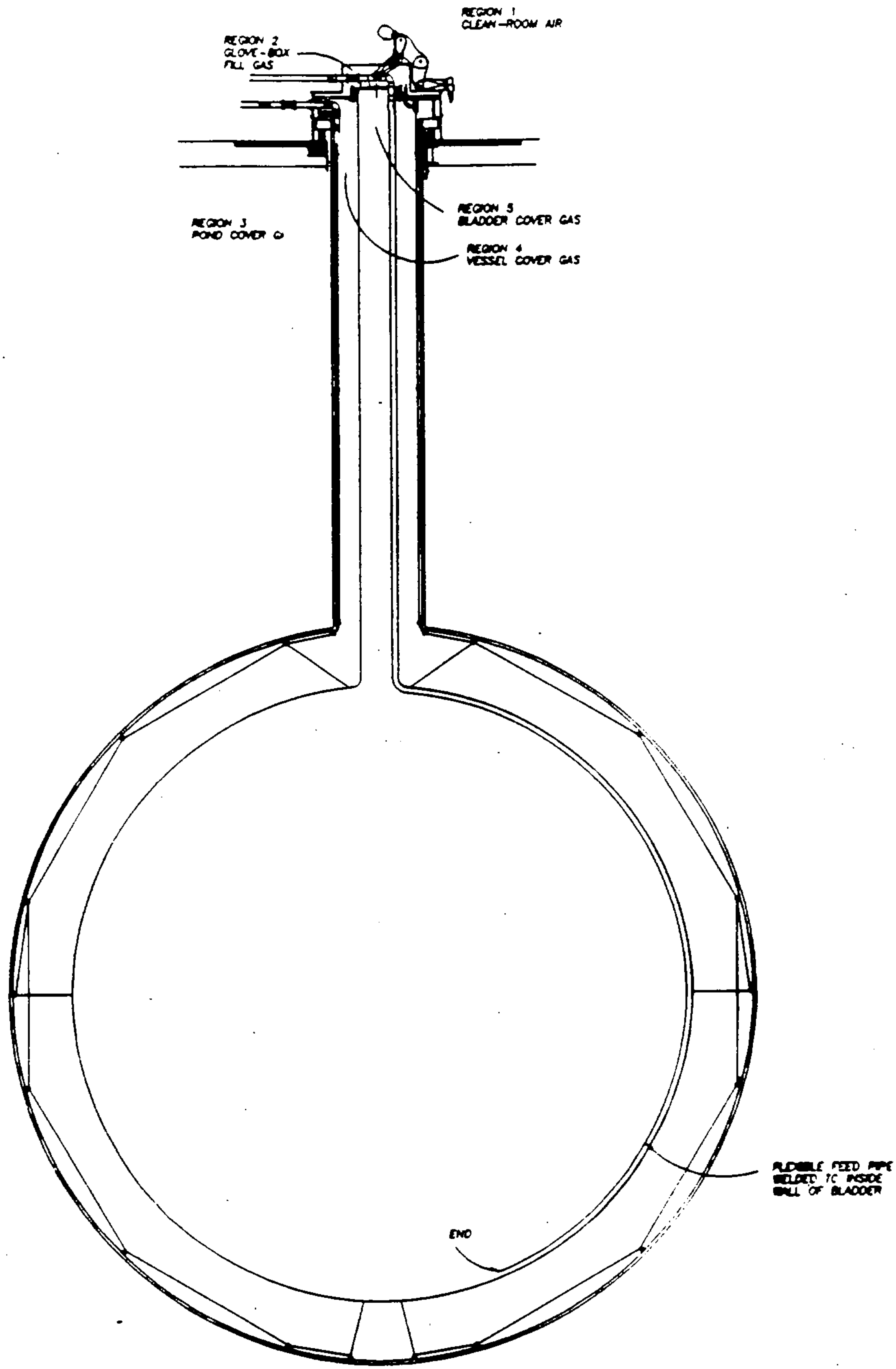
The outer region helps to eliminate NC background signals originating from the acrylic vessel, light-water, PMT & reflector assembly, liner and rock.

This configuration allows simultaneous monitoring of all 3 nu-induced signals. For 5m radius bladder we get:

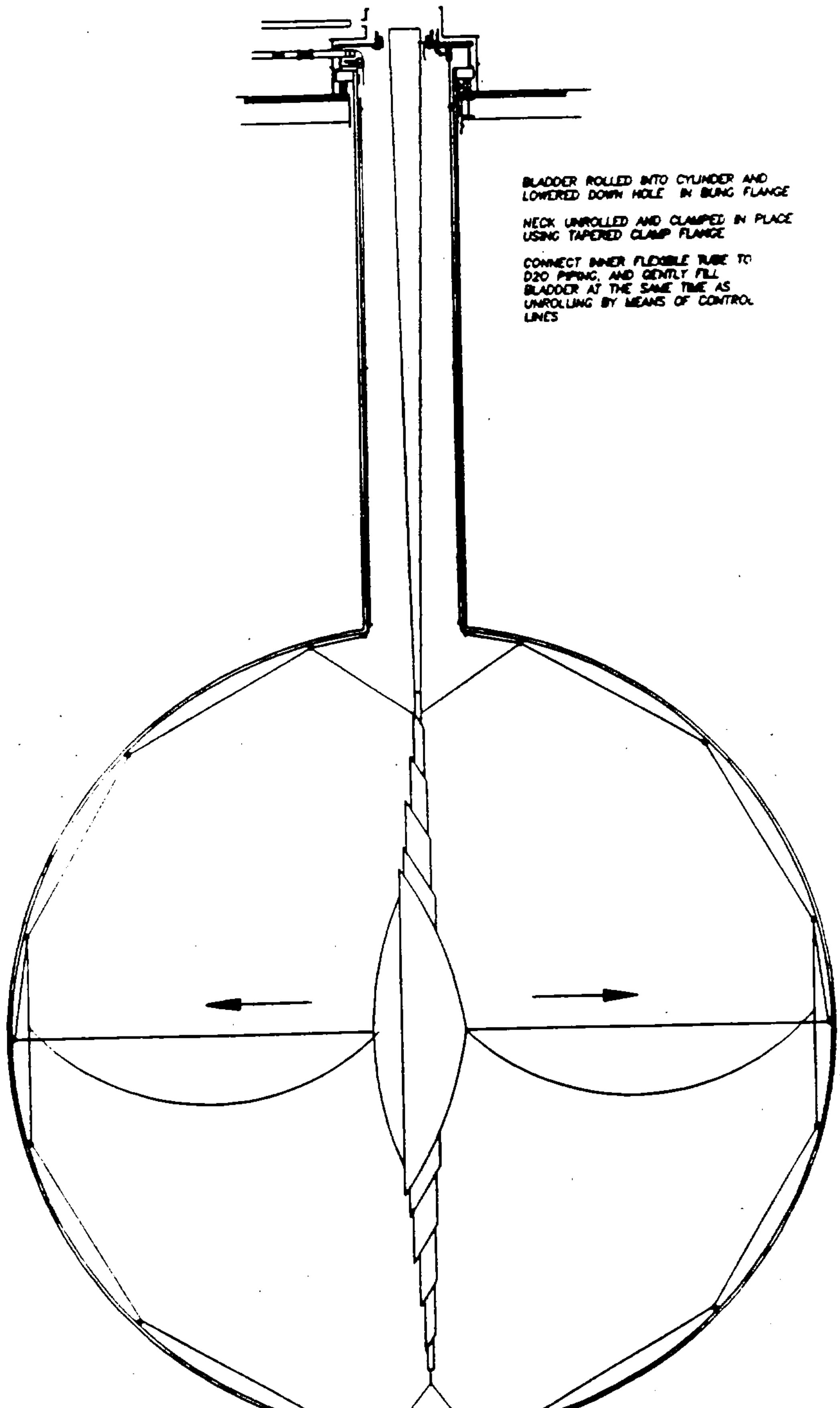
1667 T H_2O	yields ES	(ES== e+nu-->e'+nu')
420 T D_2O + ^{10}B	yields ES+CC	(CC== d+nu-->p+p+e)
580 T D_2O + NaCl	yields ES+CC+N	(NC== d+nu-->n+p+nu')

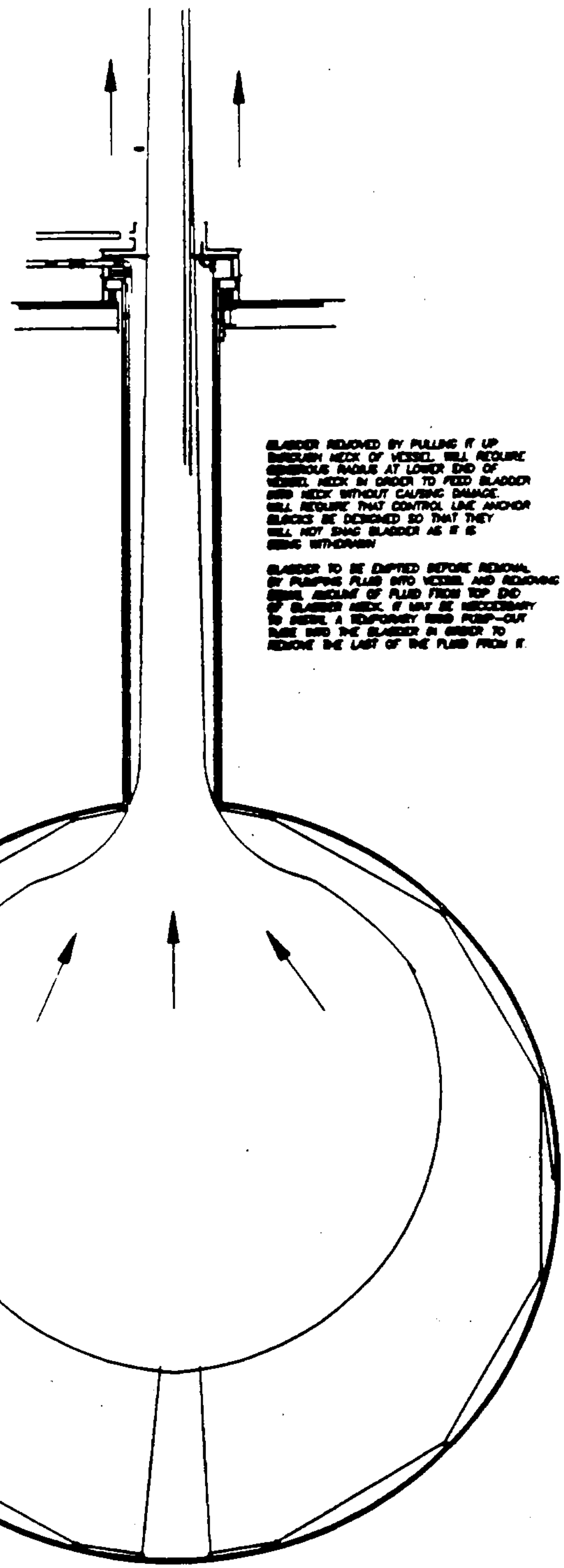


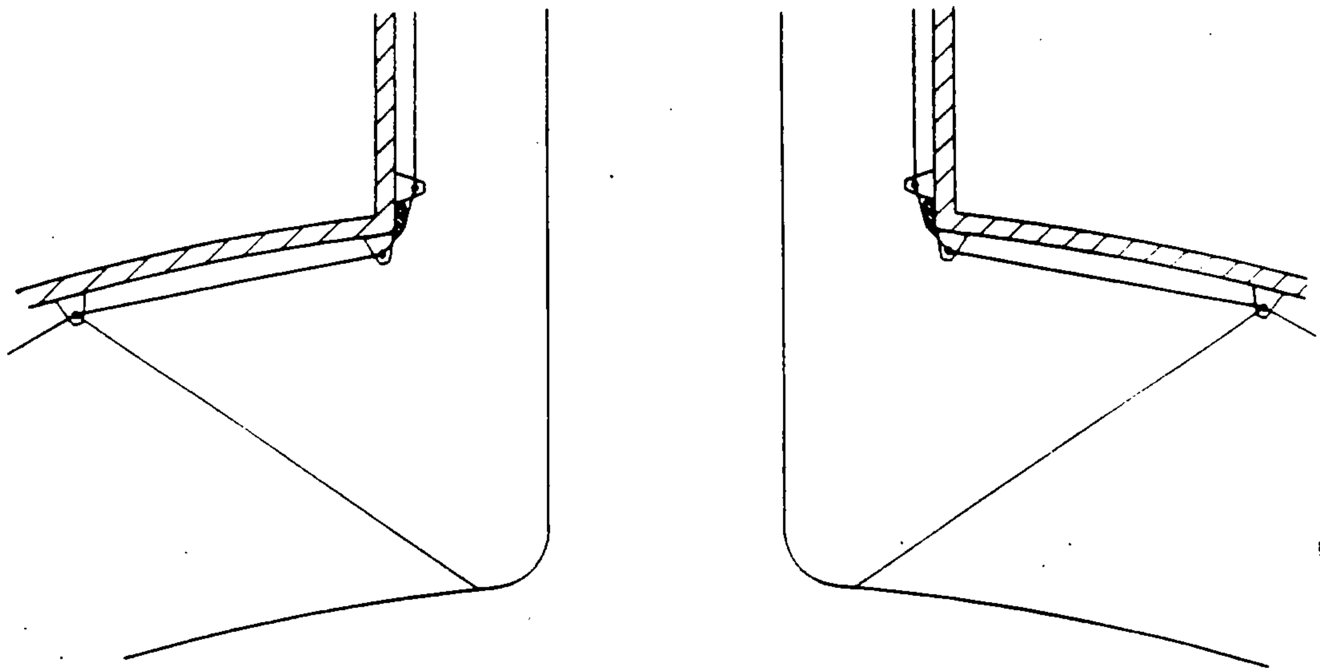
384"
TOP CONTROL LINES (4) ATTACHED
TO PATCHES ON TRANSITION PATCH
SPHERICAL BLADDER 383.7" DIA (NOM)
FORMED BY WELDING TOGETHER
20 EQUAL SECTOR PANELS.
CONTROL LINES (8)
TO PATCHES ON
SECTOR PANELS
18"
END OF FILL TUBE
BOTTOM CONTROL LINES (4) ATTACHED
TO PATCHES ON SOUTH POLE PATCH
AND ALIGNED WITH TOP CONTROL LINES

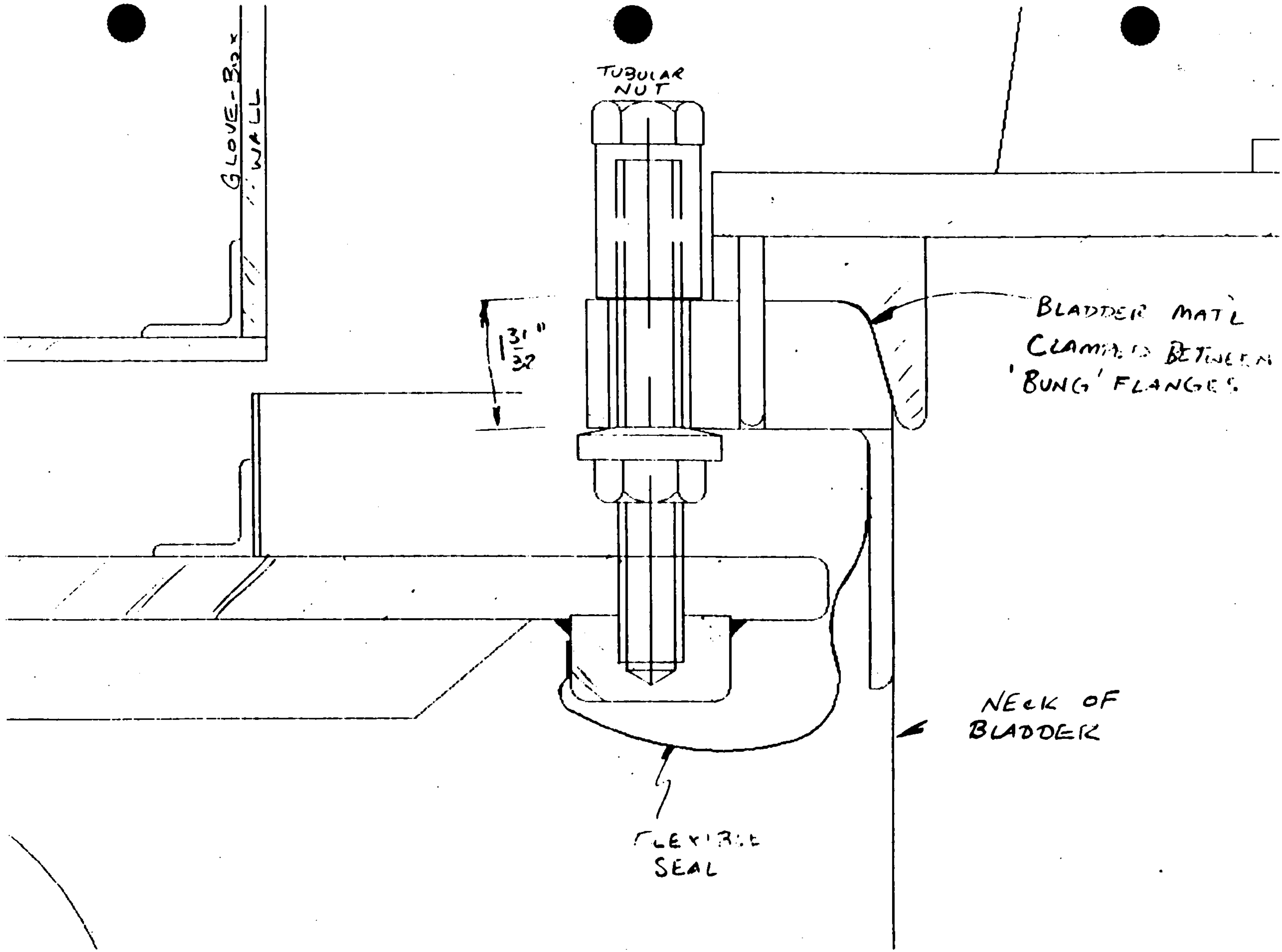


REGION 1
CLEAN-ROOM AIR
REGION 2
GLOVE-BOX
FILL GAS
REGION 5
BLADDER COVER GAS
REGION 3
POND COVER
REGION 4
VESSEL COVER GAS
FLEXIBLE FEED PIPE
WELDED TO INSIDE
WALL OF BLADDER
END


BLADDER ROLLED INTO CYLINDER AND LOWERED DOWN HOLE IN BUNG FLANGE
NECK UNROLLED AND CLAMPED IN PLACE USING TAPERED CLAMP FLANGE
CONNECT INNER FLEXIBLE TUBE TO D2O PIPING, AND GENTLY FILL BLADDER AT THE SAME TIME AS UNROLLING BY MEANS OF CONTROL LINES


BLADDER REMOVED BY PULLING IT UP THROUGH NECK OF VESSEL. WILL REQUIRE GENEROUS RADIUS AT LOWER END OF VESSEL NECK IN ORDER TO FEED BLADDER INTO NECK WITHOUT CAUSING DAMAGE. WILL REQUIRE THAT CONTROL LINE ANCHOR BLOCKS BE DESIGNED SO THAT THEY WILL NOT SNAG BLADDER AS IT IS BEING WITHDRAWN
BLADDER TO BE EMPTIED BEFORE REMOVAL BY PUMPING FLUID INTO VESSEL AND REMOVING SMALL AMOUNT OF FLUID FROM TOP END OF BLADDER NECK. IT MAY BE NECESSARY TO INSTALL A TEMPORARY RIGID PUMP-OUT TUBE INTO THE BLADDER IN ORDER TO REMOVE THE LAST OF THE FLUID FROM IT.





GLOVE-BOX WALL
TUBULAR NUT
1 31/32"
BLADDER MAT'L CLAMPED BETWEEN 'BUNG' FLANGES
NECK OF BLADDER
FLEXIBLE SEAL

Table I*

	TEFLON	TEDLAR	ACLAR	CH2	C3H6	EVA
Specfic Gravity	2.15	1.5(2)	2.1(5)	0.95	0.91	0.94
Bursting Strength pt/mil	11	19-70	23-31	11	---	11
Tearing Strength g/mil	125	12-100	2-40	15-300	7-10	50-300
Folding Endurance D2167-63T	4K	5K-47K	Good	V.high	Excl.	V.high
Water Resist. E96-63T	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.
Water Abs. %	<0.01	<0.5	nil	nil	<0.005	<0.01
Water Vapour trans. g/100in^2/mil @ 38C	0.4	3	.040(15)	0.3	0.40(5)	14
Permeability cc/100in^2/mil /d/atm @ 25C CO2	1670	11	16-40	580	370	6000
H2	2200	58	220-330	400	850	---
N2	320	0.25	2.5	42	25,c<1	400
O2	750	3	7-15	185	120,c<1	840
Refractive Index	1.34(1)	<---------1.4 to 1.5 --------->				

TEFLON= FEP fluoroplastic
TEDLAR= Polyvinyl fluoride
ACLAR = Polytrifluorochloroethylene copolymer
CH2 = Polyethylene (high density)
C3H6 = Polypropylene (c=saran coated)
EVA = Ethylene vinyl acetate copolymer

(*) Data from "Guide to Plastics", by Editors of "Modern Plastics Encyclopedia", (McGraw-Hill, Inc.)

TEFLON — T²* FILM — TEFZEL

TENSILIZED AND TOUGHENED FILM

T² stronger than normal FEP

TYPICAL PROPERTIES

T² FILMS OF "TEFLON" PFA FLUOROCARBON RESIN

PROPERTY	TEST METHOD ASTM	TYPICAL VALUE SI Units MD/TD(a)	TYPICAL VALUE English Units MD/TD(a)
Mechanical			
Tensile Strength at Break	D-882	69/24 MPa	10,000/3,500 psi
Elongation at Break	D-882	60/450%	60/450%
Elastic Modulus	D-882	760/1400 MPa	110,000/210,000 psi
Tensile Creep (1,500 psi /1000 hr)	-	4/15%	4/15%
Tear Strength - Propagating (b)	D-1922	1.8/0.9 N	0.4/0.2 lb
Impact Resistance	D-3420B	24 J/mm	5.3 in-lb/mil
Thermal			
Melt Point	DTA	304°C	580°F
Service Temperature - Continuous	-	260°C	500°F
Oxygen Index	D-2863	95%	95%
Dimensional Stability - Type M	Du Pont		
200°C (392°F)		2.0/0.8%	2.0/0.8%
250°C (482°F)		4.0/1.2%	4.0/1.2%
Shrinkage 250°C (Heat Shrink Type)		40/5%	40/5%
Electrical			
Dielectric Strength (b)	D-149(A)	160 kV/mm	4000 V/mil
Dielectric Constant	D-150 (1 khz)	2.1	2.1
Dissipation Factor	D-150 (1 khz)	0.0002	0.0002

(a) MD = Machine Direction
    TD = Transverse Direction

(b) Film Thickness is 0.0508mm (0.002 inches)

T² Films are uniaxially oriented by a patented Du Pont process that improves mechanical properties, dimensional stability, and impermeability. Many improvements are made in both the machine direction and transverse direction.

TECHNICAL INFORMATION

DU PONT TEFLON® FEP FLUOROCARBON FILM

BULLETIN T-5A

OPTICAL

OPTICAL PROPERTIES

LIGHT TRANSMISSION

"Teflon"* FEP fluorocarbon film transmits more ultraviolet, visible light and infrared radiation than does ordinary window glass. Figures 1 and 2 show the light transmission and absorbence of 1 and 5 mil "Teflon" FEP vs. ordinary window glass. It will be noted that "Teflon" FEP is much more transparent to the infrared spectrum than is glass and also transmits more of the ultraviolet range. Since transmittance and absorbence are reciprocal functions, they are both plotted as ordinates in Figures 1 and 2.

Figure 1

ABSORPTION SPECTRUM FOR "TEFLON" FEP FILM

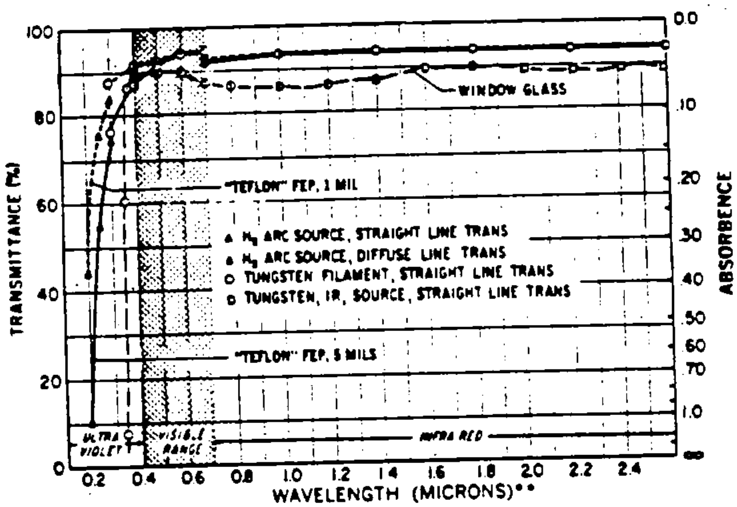
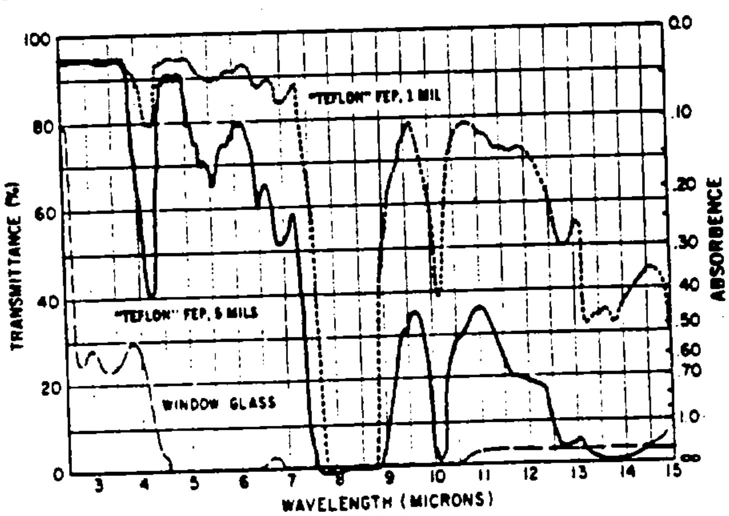


Figure 2

ABSORPTION SPECTRUM FOR "TEFLON" FEP FILM



REFRACTIVE INDEX

The refractive index of "Teflon" FEP film is between 1.341 and 1.347.

*Reg. U.S. Pat. Off.

**1 Micron = 10,000 Angstroms = 0.001 mm

Questions B & C: *What is the signal for the SSM? (Assume 5000 NC interactions per KT-Y.)*

First, look at models for n-capture γ decays (averaged from NDS):

D_2O:
****
```
 E1=6.25
```

NaCl:
*****
```
 P=rnd
 If (P<.046) E1=8.6, goto end
 If (P<.160) E1=6.1, E2=1.2, E3=0.8, E4=0.5, goto end
 If (P<.278) E1=5.6, E2=3.0, goto end
 If (P<.512) E1=6.1, E2=2.0, E3=0.5, goto end
             E1=7.4, E2=1.2
end:
```

Gd(a): Gd(b):
****** ******
```
        E0=8.0
 E1=Rnd*E0      or      E1=4+Rnd*4
        E2=Rnd*(E0-E1)
        E3=Rnd*(E0-E1-E2)
        E4=Rnd*(E0-E1-E2-E3)
        E5=(E0-E1-E2-E3-E4)
```

Cd:
***
```
  P=Rnd
 E0=9.043
 If (P<.048) E1=8.80, goto bot     Bot:
 If (P<.161) E1=7.68, goto bot      E2=Rnd*(E0-E1)
 If (P<.345) E1=6.33, goto bot      E3=Rnd*(E0-E1-E2)  or E3=E0-E1-E2
 If (P<.732) E1=5.83, goto bot      E4=E0-E1-E2-E3     or E4=0
             E1=5.55, goto bot      E5=0               or E5=0
```

Then compton scatter & look at compton electrons. Cerenkov light output based on plot in Annex 15, scaled to 55% coverage & 24% ave PMT efficiency:

\# of photons created = (Ee*116.5-106)
\# of photons detected = #created * 0.10

pmt eff	=0.24	(WB)
coverage	=0.55	(WB)
D_2O trans	=0.87	(WB)
Acrylic trans	= 0.90(*)	(WB)
H_2O trans	= 0.98	(WB)

----

net photon collection efficiency = 0.10

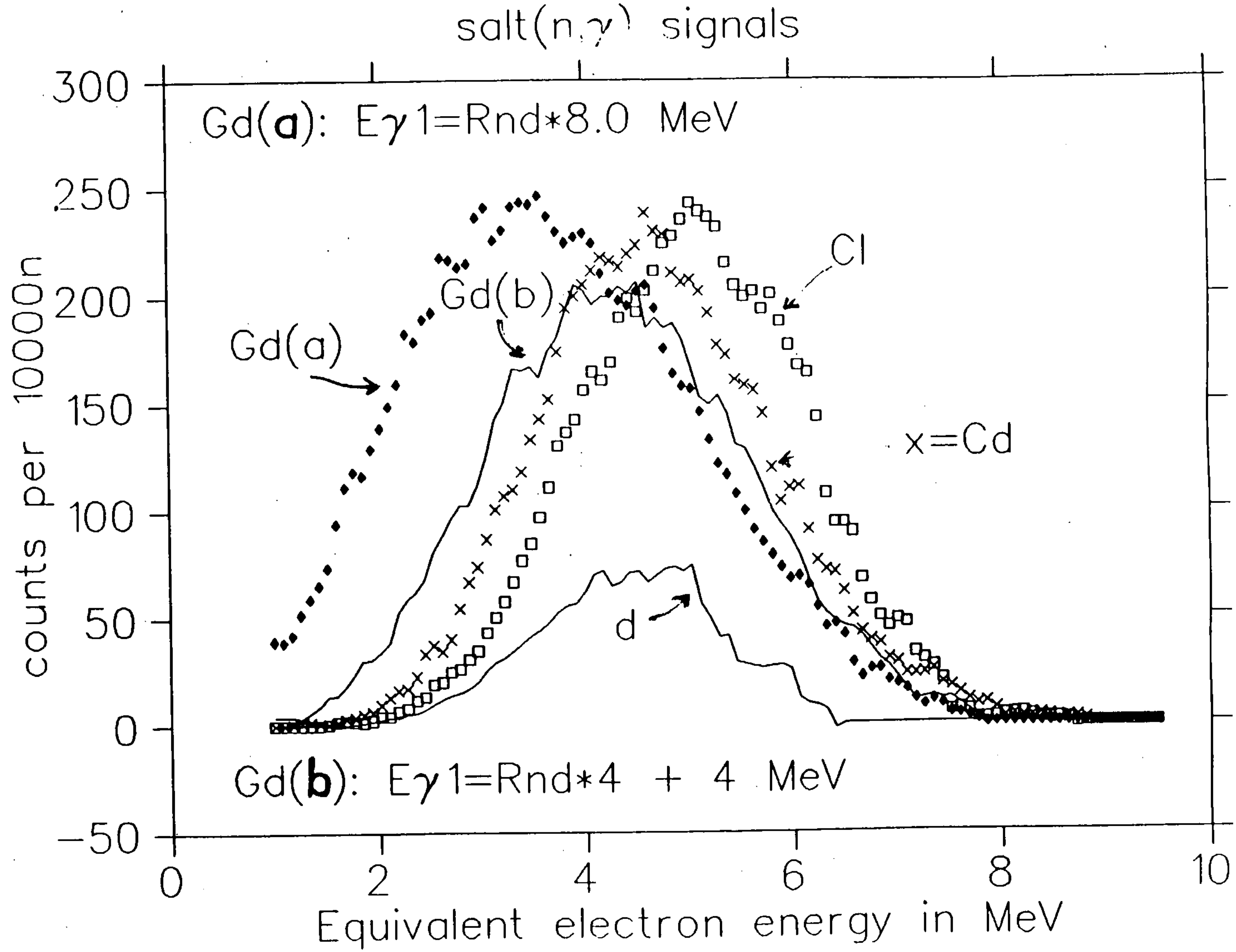
Fraction of hits above threshold (FT):

	4.5 MeV	5.0 MeV	x-section	amount
D_2O	0.48	0.26	0.5 mb	1KT
NaCl	0.70	0.52	34 b	2.5 T /KT D_2O
Gd(a)	0.29	0.18	49 Kb (^{nat}Gd)	4.6 Kg/KT D_2O
Gd(b)	0.45	0.30	260 Kb (^{157}Gd)	0.9 Kg/KT D_2O
Cd(4g)	0.56	0.38	2 Kb (^{nat}Cd)	82. Kg/KT D_2O
Cd(3g)	0.62	0.43	20 Kb (^{113}Cd)	8.2 Kg/KT D_2O

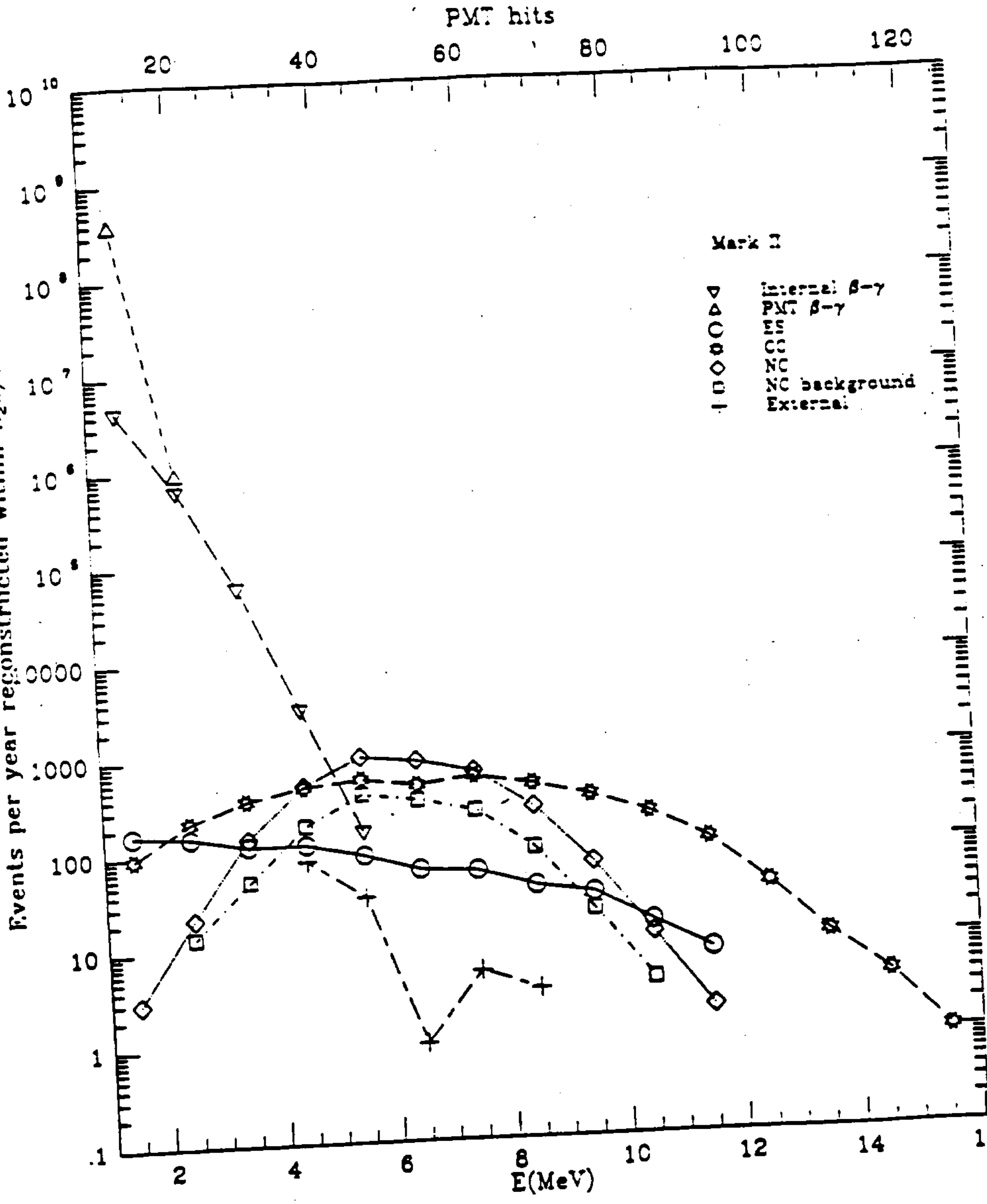
Capture prob. per total vol.

\# of NC events seen given 5000/KT-/Yr = $\frac{5000 * R^3 * CP * FT}{6^3}$

R	CP D_2O	CP Salt	E>4.5MeV D_2O	E>4.5MeV NaCl	E>4.5MeV Gd^b	E>4.5MeV Cd^3	E>5.0MeV D_2O	E>5.0MeV NaCl	E>5.0MeV Gd^b	E>5.0MeV Cd^3	n(BK)/n(v)
3m	0.16	0.69	50	300	190	270	30	220	130	190	0.25
4m	0.18	0.72	130	750	480	660	70	560	320	460	0.25
4.5	0.19	0.73	170	1080	700	960	100	800	460	660	0.26
5m	0.19	0.74	270	1500	970	1330	140	1080	640	920	0.29
6m	0.20	0.75	480	2640	1700	2340	260	1960	1130	1630	0.49


salt(n,γ) signals
Gd(a): Eγ1=Rnd*8.0 MeV
Gd(b): Eγ1=Rnd*4 + 4 MeV
Gd(a)
Gd(b)
Cl
x=Cd
d
counts per 10000n
Equivalent electron energy in MeV
300
250
200
150
100
50
0
−50
0
2
4
6
8
10

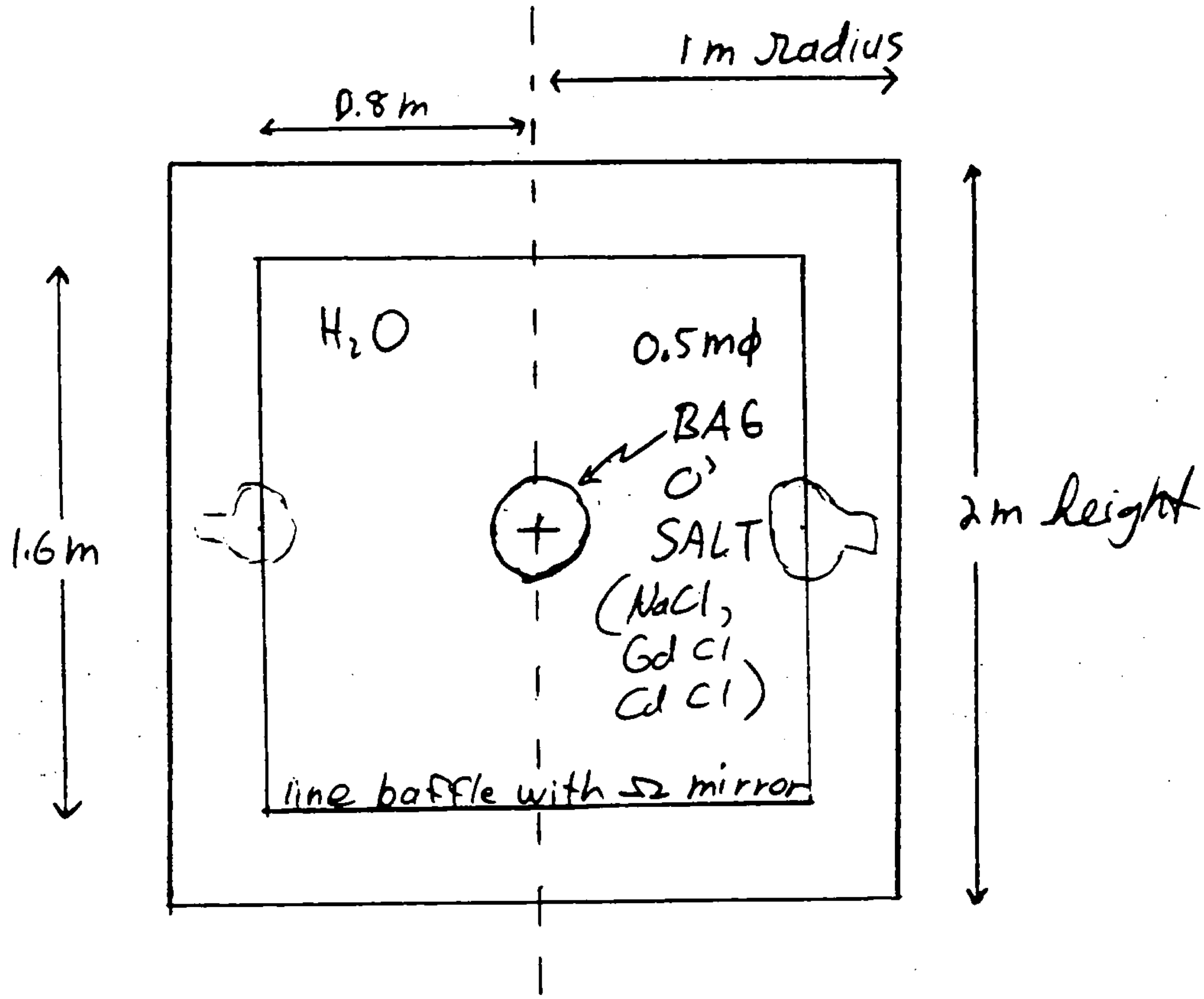
$D_2O + NaCl$



DOE/NSERC/NRC Report Oct/89

Cd & Gd (n,γ) schemes complicated!

⟹ suggest actually measure Čerenkov light : MK II TEST CH.



2 m cylinder : tot. vol = 6.3 m^3 ≡ 6.3 T H_2O

inner vol = 3.2 m^3

inner area = 3.8 π m^2

area/pmt = { 0.01 π m^2 flat ; 0.02 π m^2 hemi.

⟹ 50 8" PMT = 0.26 (Ω) * 0.24 (ε) * 3.6 (Refl)

≡ 22% collection

(= 2 * SNO)

Question C: - *What are all the known sources of background? How will they be determined? If possible, make an estimate of the absolute precision of measurement of the NC flux per year, ignoring uncertainties in the number 5000. Include estimates for known sources of systematic uncertainty.*

D_2O @ 0.011 ppt U & Th	== 3.0 n/d = 1095 n/Yr	
Acrylic @ 2 ppt U & 1 ppt Th	== 4.0 n/d = 1460 n/Yr	(near vessel)
1mil bladder @ 10 ppt U & Th	== 0.04 n/d = 15 n/Yr	
H2O	== 0.2 n/d = 73 n/Yr	(near vessel)
PMT	== 0.1 n/d = 37 n/Yr	"
Al-reflectors	== 0.01 n/d = 4 n/Yr	"
Stainless Steel liner & rock	== <0.25 n/d = <91 n/Yr	"

D_2O background scales with volume ($1095*R^3/6^3$) inside & remainder is attenuated by Boron n-absorbtion & D_2O γ attenuation & raytracing external background is attenuated by additional γ & neutron absorbtion (using conservative factor of 10 attenuation per meter).

BELOW 5M RADIUS THE NC BACKGROUND IS DOMINATED BY THE RADIOIMPURITIES IN THE HEAVY WATER ITSELF!

Background from dissolved radioimpurites could be monitored during initial gradual removal by plotting rates vs. U & Th concentrations.

Additional sources of background:

The effect of $F(\alpha,n)$ (Q=-2.0MeV) and $F(\alpha,p+\gamma>2.2)$ (Q=+1.7MeV) needs to be investigated if using TEFLON bladder.

Mass for 5m radius TEFLON bladder is 17.2 Kg per mil thickness, 72% of which is fluorine, or 12.4 Kg per mil.

The backgrounds do not include the High Energy γ flux,which is identical to that presented in the WB, annex,and 1989 DOE/NSERC/NRC presentation for the standard Mark-II vessel with and without NaCl or Gd additives.

Question D: *Question D: - List the necessary radiopurities of materials and describe the production and measurement programs needed to achieve them.*

- Mass of TEFLON (or other plastic) is quite small. Initially, the thickness and radioimpurity levels were determined by assuming a contribution to NC background not to exceed that produced by a 1 ppt U & Th contamination in the acrylic vessel, attenuated by 1m of water.

- A 500g sample of 1mil TEFLON FEP film was radioassayed (Simpson et al.): no evidence of U or Th was found, with an upper limit placed at <12 ppt. Telfon is expected to be at least as pure than acrylic because teflon contains no added stabilizers or polymer-chain inhibiters.

- Even for a 10mil thick bladder at 10 ppt, the contribution to NC background will not exceed that of the acrylic (now deemed to be 2 ppt U & Th); Obviously, with a more realistic value of 1 mil film at 1 ppt, there is no impact to NC background.

- A similar argument holds true for the NYLON tether lines used to anchor the bladder, especially since the bulk of the tether lines remain at the acrylic vessel.

- α-induced reactions on Fluorine should be investigated to verify if they make only a small contribution

Question E: *Describe calibrations*

The bladder is designed to accommodate the "standard" SNO e, γ, and n sources. The largest source that must fit through the bladder's neck is the High Energy $_3$He+n γ source, which poses a constraint on the minimum diameter of the bladder's neck.

Since the bladder maintains spherical symmetry (default shape is 5m radius sphere), post-insertion scanning of efficiency with position need only be done in the vertical direction.

Question F: *How does the method affect CC signal recovery from the ?*

- The CC signal is not at all adversely affected. In fact, it is enhanced: the region between the vessel and bladder is sensitive only to CC+ES, whereas the region within the bladder sees NC+CC+ES.

Question G: *List the ways in which the method affects the design and construction of the acrylic vessel.*

Anchors for the tether lines must be installed inside the acrylic vessel. Their design is similar to the ring + footplate as proposed by the $_3$He detector group (20Kg Force/plate * 220 plates = 4.4T Force total on vessel).

In the scenario that 1.45T NaCl (2.5T*0.58) will be used in the inner region, then 1.07 T of solute (containing boric acid) must be added to the region outside the bladder to achieve overall neutral buoyancy. Since a slight overpressure within the bladder may be desirable to maintain shape rigidity, the 1.07T could be reduced, limited by the loading on the bladder by the tethers. The static load that must be borne by the acrylic vessel is considerably less than that imposed by the $_3$He counters.

A dynamic load will be imposed on the tethers and their anchors during careful insertion of the bladder. Since this load is limited by the more fragile nature of the bladder, the impact of loading on the vessel should be negligible.

See section E for impact on calibration systems.

Question H: *List the ways in which the method affects the design and construction of the water treatment systems.*

Provision has been made for water-recirculation on either side of the bladder, thus allowing for continual scrubbing of undesired contaminants. This removes necessity of relying exclusively on cleanliness of both the bladder and the heavywater prior to insertion.

- provision made for two heavywater systems (one is awkward but possible)

- impact of additives H_3BO_3 and either 1.45T NaCl, 2.7Kg ^{nat}Gd, 0.5Kg ^{157}Gd, 38Kg ^{nat}Cd, or 4.7Kg ^{113}Cd (+ complimentary ions)

- salts will have to be removed from D_2O at completion of SNO

- may need to scrub out opposite salt & reintroduce it to the appropriate side

(No hard data available yet on ion permeability, but will measure;
if assume ion transport is similar to water vapour transmission in TEFLON T2 film (4g/m^2/d/mil), then for 1mil film we get:

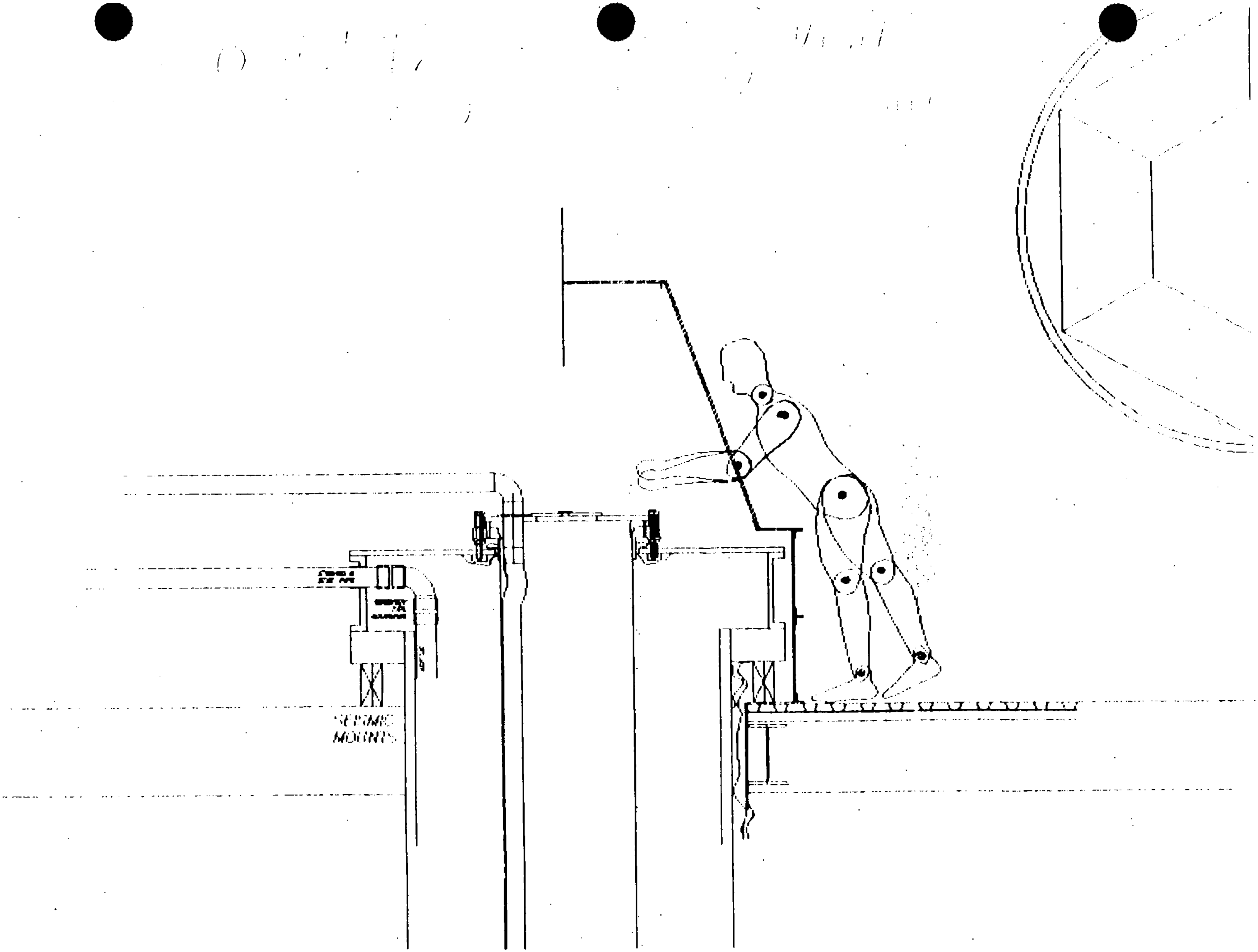
in-->out: 1.1Kg/Y NaCl, 29g/Y Cd, 4g/Y ^{113}Cd, 2g/y Gd, or 0.4g/Y ^{157}Gd
out-->in: 9g/Y ^{nat}B or 2g/Y ^{10}B.

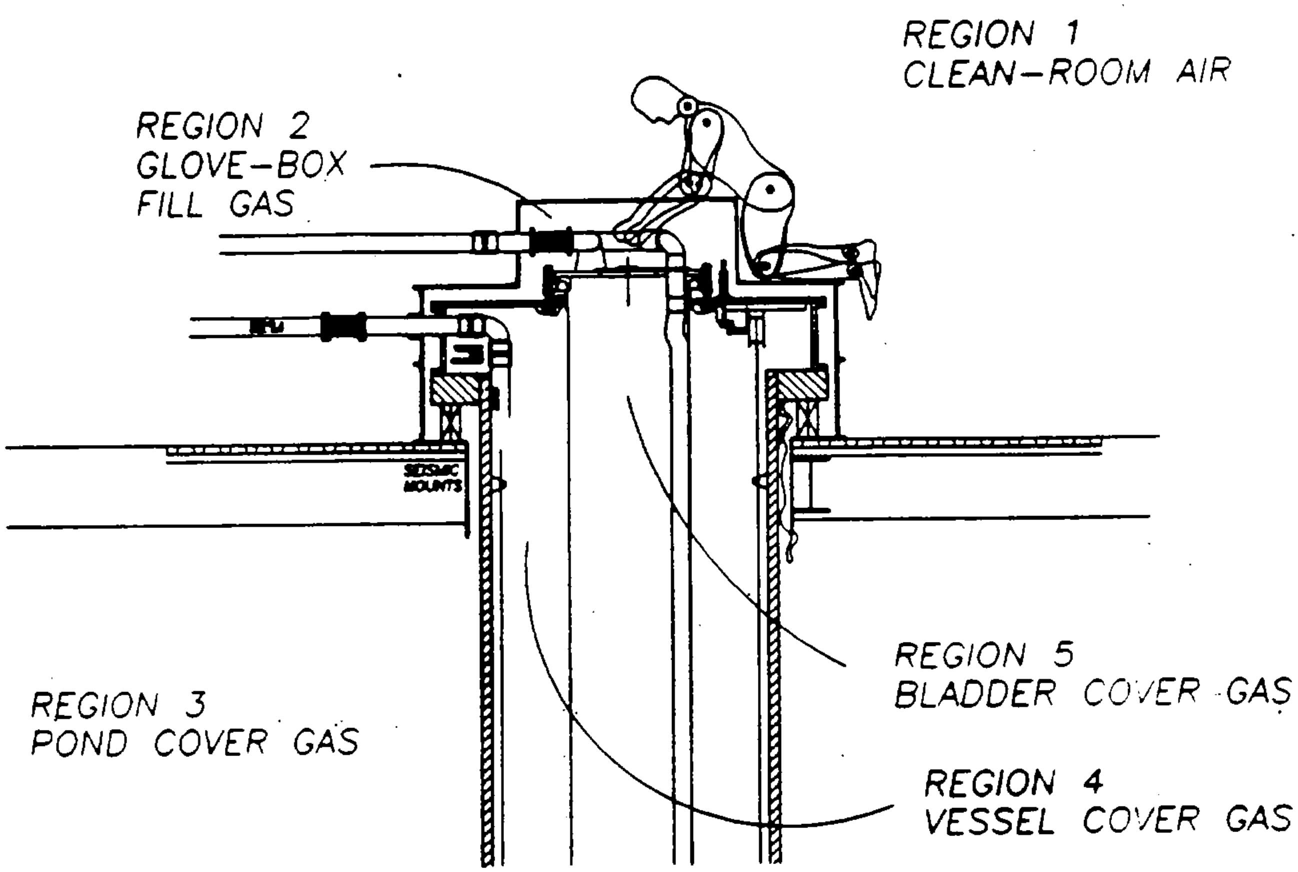
In terms of cross-section weighings, amount of salt to boron outside is 0.1%/year, and amount of boron to salt inside is 0.08%/year, so salt-separation would not be necessary over the operational life of SNO.)

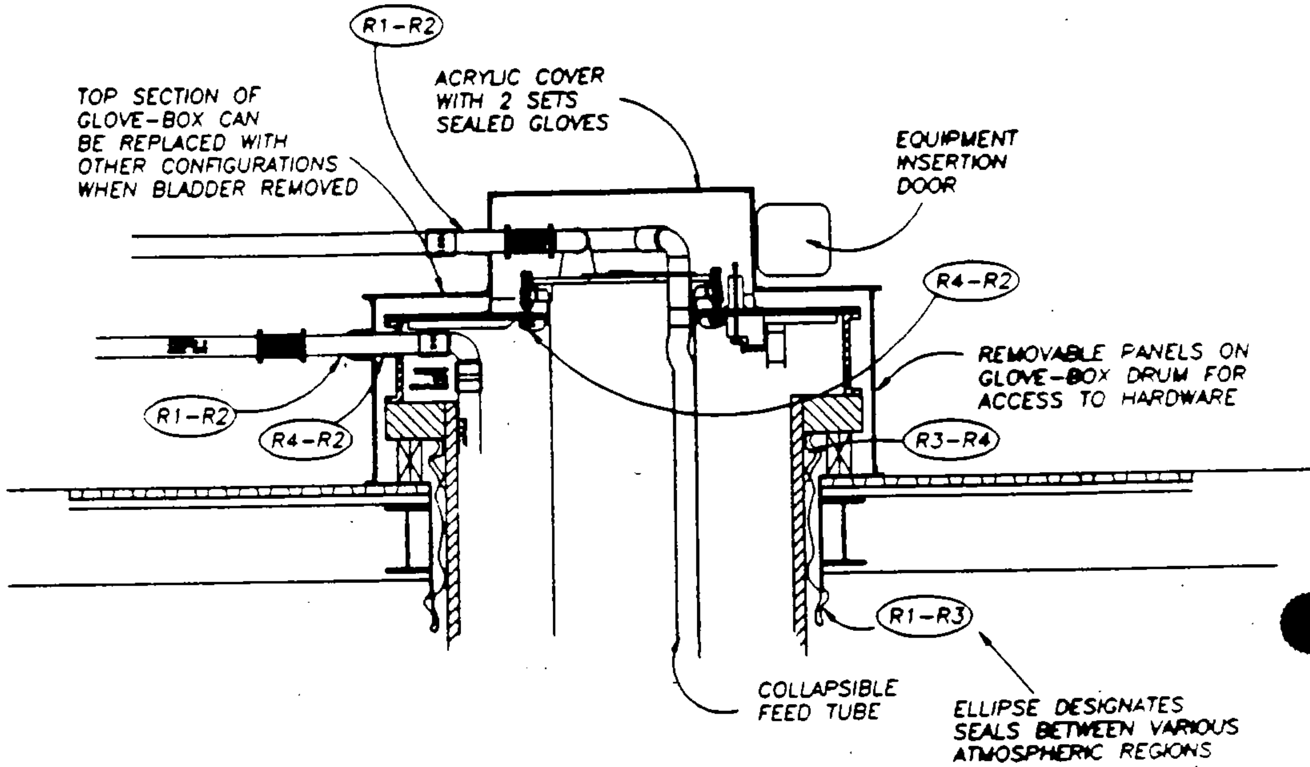
Question I: *List the Monte Carlo calculations that will be needed before proof-of-principle*

First order information already available from WB, Annex (1&7), DOE/NSERC/NRC, because using spherical symmetry & TEFLON is transparent & adds no re-scattering from RI mismatch, so proof-of-principle is already established.

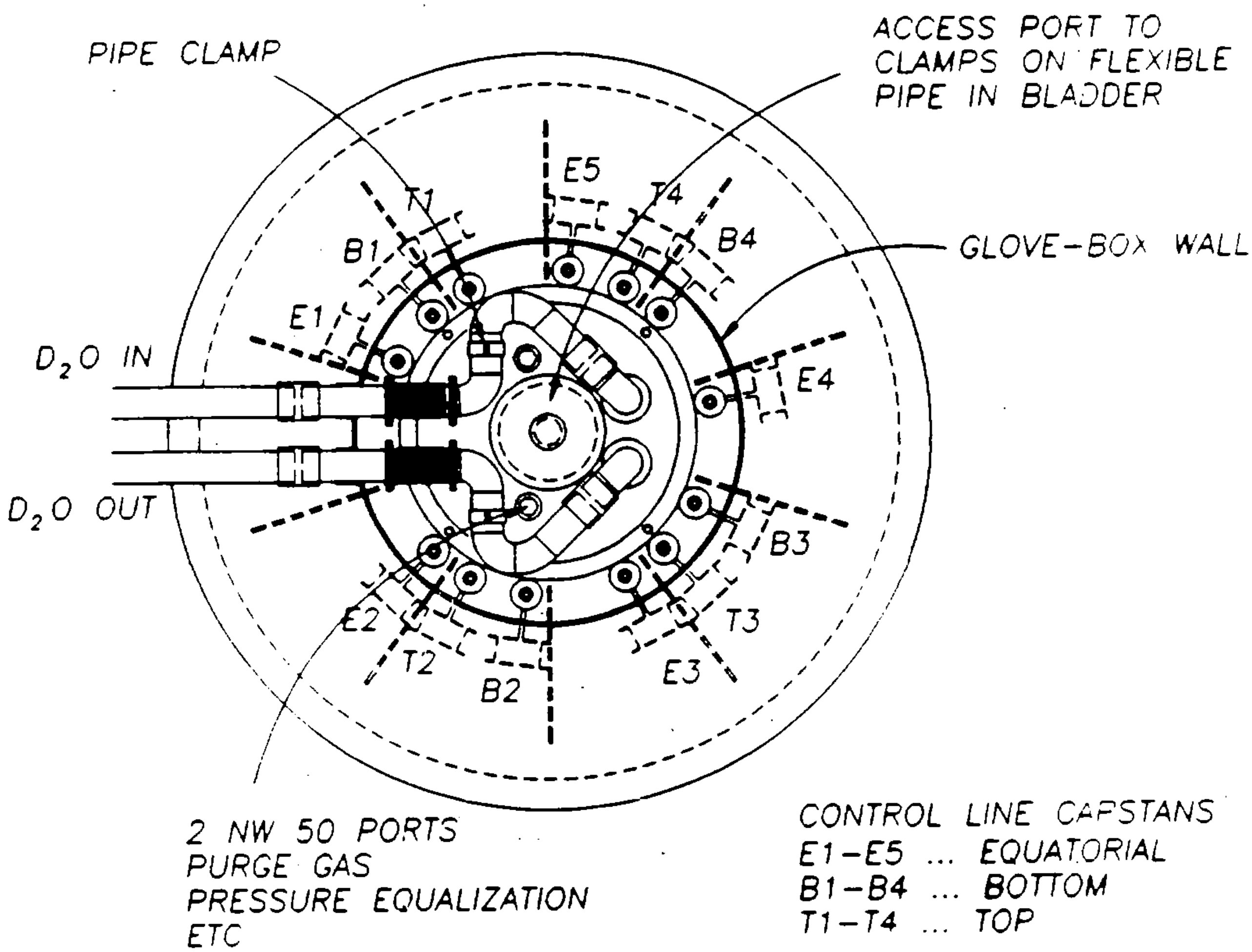
The use of more conventional transparent plastics (RI=1.45 to 1.5) will double the effect from the acrylic on RI surface scattering, or 2*15%, so second-order MC would still be desirable (+ traceback resolution, threshold shapes, etc.).


SEISMIC
MOUNTS

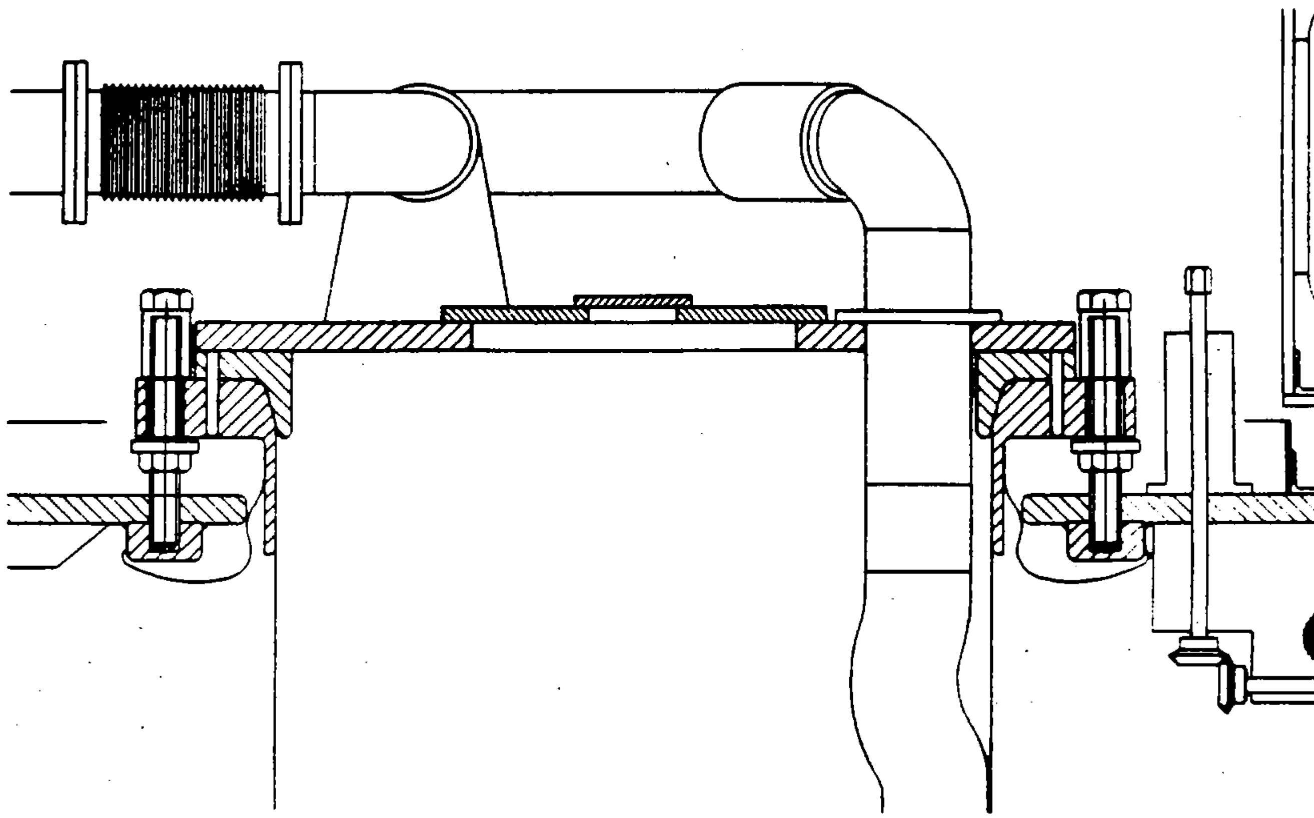

REGION 1
CLEAN-ROOM AIR
REGION 2
GLOVE-BOX
FILL GAS
SEISMIC
MOUNTS
REGION 3
POND COVER GAS
REGION 5
BLADDER COVER GAS
REGION 4
VESSEL COVER GAS

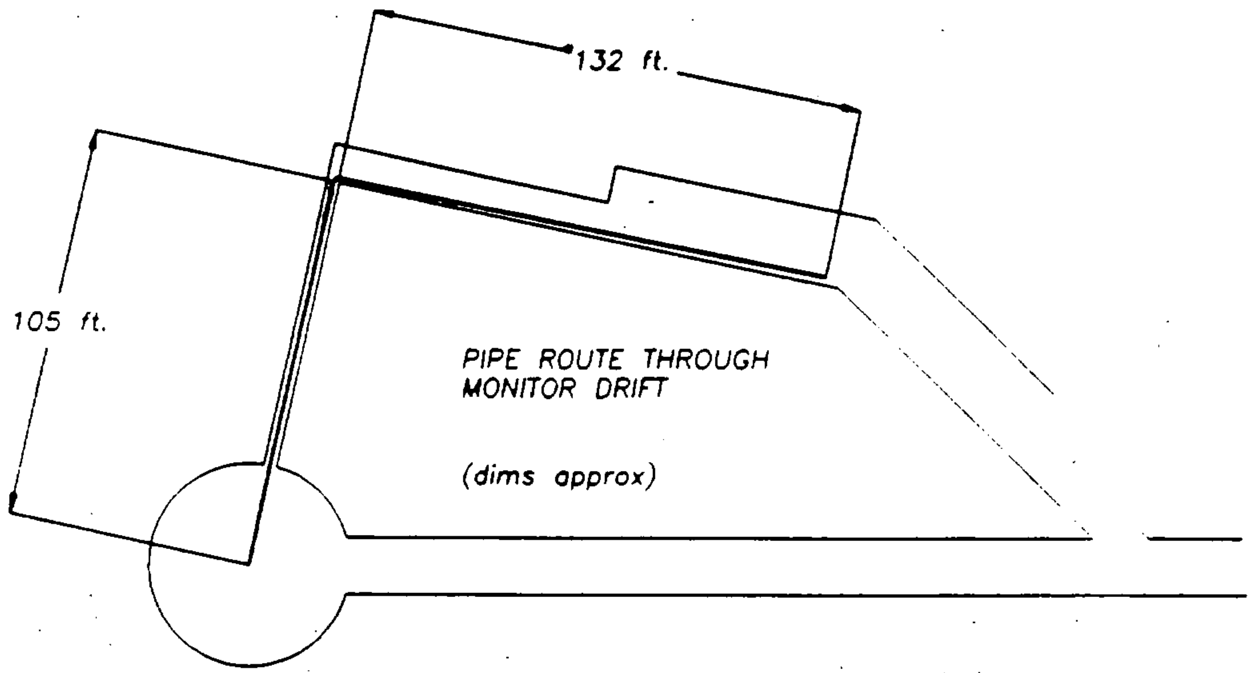


R1-R2
TOP SECTION OF GLOVE-BOX CAN BE REPLACED WITH OTHER CONFIGURATIONS WHEN BLADDER REMOVED
ACRYLIC COVER WITH 2 SETS SEALED GLOVES
EQUIPMENT INSERTION DOOR
R4-R2
REMOVABLE PANELS ON GLOVE-BOX DRUM FOR ACCESS TO HARDWARE
R1-R2
R4-R2
R3-R4
R1-R3
COLLAPSIBLE FEED TUBE
ELLIPSE DESIGNATES SEALS BETWEEN VARIOUS ATMOSPHERIC REGIONS



NB: will need to enlarge access
port to accommodate
(^3He + n) 20 MeV γ source




132 ft.
105 ft.
PIPE ROUTE THROUGH
MONITOR DRIFT
(dims approx)

Question J: List the engineering calculations (stress, fracture, etc.) needed before proof-of-principle

Present design of the vessel structure calls for support system to bear loads and handling from $_3$He counter array; again, first order calculations of the bladder system indicate a much smaller impact on vessel structure.

Winzen Co. Ltd, Sulphur Springs, TX and American Durafilm Ltd., Holliston, MA, are two manufactures interested in building the (TEFLON) bladder. The former has the world's greatest expertise on dynamics of large, thin, flexible and loaded membranes, as they research and construct balloons up to 100,000 m^3 or greater; they are capable and willing to do stress, fracture, seam, etc. analyses.

Question K: List the people who will be working on the system R&D and how much time they will spend.

Manpower for Spherical Bladder Design:

R.B. Schubank	UBC Research Associate	full-time (<30/6/91; then ??)
C.E. Waltham	UBC Assistant Professor	part-time
L. McGarry	UBC MSc student	full-time
A. Morgan	Van. Eng. Consultant	part-time

+ consultations with:
E. Jernigan of American Durafilm, Holliston, MA
L. Sealy of Winzen Co., Sulphur Springs, TX

Possible collaboration with J. Simpson & Princeton Group to investigate Split-vessel / hemi-spherical bladder compromise.