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ACCELERATOR DEPARTMENT
Informal Report

ISABELLE VACUUM PUMPING SYSTEM

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March 27, 1972

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INTERSECTING STORAGE ACCELERATOR NOTES

ISABELLE VACUUM SYSTEM Vacuum Pumping System

P. Grand

April 6, 1972

Introduction:

CRISP Notes 71-49 and 72-7 outline the vacuum requirements for ISABELLE and the parameters we have to meet with the pumping system. This note describes the proposed general layout for the ISABELLE Vacuum Pumping System. It proposes the use of cryosorption pumping to achieve the required operating pressure of $<10^{-10}$ torr. A pump design is described to meet this requirement.

Although initially it was thought that pumping at the end of each dewar (~12 m) would be sufficient to achieve the desired pressure, it has become evident that the beam pipe aperture (5 cm) will not permit it and that a pump is required at each magnet.

Engineering Parameters: In normal operation the beam pipe will be cooled to 4.5°K. However, to design the vacuum system we have to consider 3 modes of operation; a) during the 300°C bake, b) at room temperature, c) at helium temperature. In order to avoid confusion, we will consider these 3 modes separately.

300°C Bake Condition: It has been established elsewhere (CRISP 71-49) that every time the vacuum chamber has been exposed to atmosphere we will bake the system to 300°C for about 24 hours. These times and temperatures are rather arbitrary and correspond to a desorption energy of about 40 Kcal/mole.

The baking process has the direct effect of drastically increasing the outgassing rate or desorption rate of adsorbed and absorbed gases. This procedure will take place with the roughing turbomolecular pumps on only, namely

beam pipes

half cell

$2L = 12m$

C

$C = 2.5 \text{ l/sec}$

C

Pump
 $S = 50 \text{ l/s}$

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$$\Delta P = \Sigma \Delta p = \frac{Q}{C} + \frac{2Q}{C} = \frac{3Q}{C}$$

$$\text{for } \Delta P = 10^{-5} \quad Q = \frac{\Delta PC}{3} = \frac{2.5 \times 10^{-5}}{3} \cong 10^{-5} \text{ torr } \ell/\text{sec}$$

If we assume at this time an outgassing rate of 10^{-12} torr $\ell/\text{sec cm}^2$, then with a total flow of $Q = 10^{-5}$ torr ℓ/sec we could accommodate an area of

$$A = 10^7 \text{ cm}^2 \text{ per sector}$$

and the pressure at the pump would be

$$P = \frac{Q \text{ total}}{S} = \frac{5Q}{S} = \frac{5 \times 10^{-5}}{50} = 10^{-6} \text{ torr}$$

From the assumptions outlined above, it is reasonable to project the roughing pump bringing the average pressure of the system down to $<10^{-5}$ torr. The resulting surface area of 10^7 cm^2 with an outgassing rate of 10^{-12} torr $\ell/\text{sec cm}^2$ seems very large. However, if we consider all surfaces including cryosorption high vacuum pumps, this number is reasonable.

Ultra-High Vacuum Operation at room temperature:

Although the beam pipe will eventually be cooled to 4.5°K during operation, it is imperative to evacuate it to its base pressure at room temperature to avoid condensing residual gases on the pipe walls. Only then will the cooling process start.

The vacuum system should therefore be able to operate both at 293°K and 4.5°K. Since these different temperatures present different problems they are treated separately.

Initially, let us consider a vacuum pump at the end of each dewar (half cell) connected to both beam pipes.

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It is expected that after baking the outgassing rate of the beam pipe will be 10^{-13} torr μ /sec cm^2 . However, in this case we will use an outgassing rate of 3×10^{-13} torr μ /sec cm^2 and consider the beam pipe as a straight, continuous pipe, 5 cm dia, without associated hardware (e.g. bellows, flanges, clearing electrodes, etc.) The conservatism in the outgassing rate will make up for the gas load due to these unknowns.

Then using the following numbers:

Outgassing rate for 1 meter length at room temperature,

$$q = 3 \times 10^{-13} \times \pi d \times 10^3 = 5 \times 10^{-10} \text{ torr } \mu/\text{sec m}$$

Conductance of 1 meter length at room temperature for N_2 and H_2 ,

$$C_{\text{N}_2} = 12.3 d^3 10^{-2} = 15.4 \mu/\text{sec for 1 meter}$$

$$C_{\text{He}} = 45 d^3 10^{-2} = 56 \mu/\text{sec for 1 meter}$$

(C will change from 15.4 to 56 μ /sec as residual N_2 is diluted by He and H_2 . However, the calculations will be for N_2)

Assuming no leaks,

$$\Delta P = \frac{qL^2}{2C} = \frac{5 \times 10^{-10} \times 36}{2 \times 15.4} \approx 5 \times 10^{-10} \text{ torr}$$

and under these conditions the pumping speed required for each pump is:

$$S = \frac{4qL}{P} = \frac{4 \times 5 \times 10^{-10} \times 6}{10^{-10}} \approx 120 \mu/\text{sec at } 10^{-10}$$

It is clear that under these conditions, if we want to achieve an average pressure $< 10^{-10}$ torr, we need to add pumps at each magnet

Half Cell

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In this case:

$$\Delta P = \frac{qL^2}{2C} = \frac{5 \times 10^{-10} \times 2.25}{2 \times 15.4} \approx 4 \times 10^{-11} \text{ torr}$$

and

$$S = \frac{4qL}{P} = \frac{4 \times 5 \times 10^{-10} \times 1.5}{10^{-10}} = 30 \text{ } \mu\text{/sec at } 10^{-10} \text{ torr}$$

These calculations consider outgassing only. If we assume that leaks can develop at joints near the pumps and that we want to be able to operate with a total leak rate of 10^{-8} torr $\mu\text{/sec}$ in the pump area, the pumping speed required becomes:

$$S = \frac{Q_0 + Q_L}{P} = \frac{3 \times 10^{-9} + 10^{-8}}{10^{-10}} = 130 \text{ } \mu\text{/sec}$$

It is clear from the above that the lowest practical pressure we can achieve at room temperature is 10^{-10} torr. Since the system is conductance limited increasing the sizes of the pumps to infinity cannot lower the average pressure $\sim 2 \times 10^{-11}$, this is obviously unrealistic as pumping speeds are limited by costs and other factors.

The residual gas density at 10^{-10} torr is about 3×10^6 molecules/cm³.

During the initial pump down the relative abundance of the various gases in the system will be directly related to their partial atmospheric pressures, however, when reaching the low pressure the gas load will be predominantly H₂ and CO, both products of outgassing.

Ultra-High Vacuum Operation at 4.5°K:

Because of beam-induced effects, it is desirable to operate the beam pipe at 4.5°K to increase the electrical conductivity of the pipe walls. Cooling the pipe can also be taken advantage of to achieve extremely low pressures $< 10^{-10}$ torr.* At 4.5°K the outgassing of materials becomes negligible and leaks become the predominant gas load.

As the beam pipe will have no joints inside the magnets, the gas load due to leaks will then be concentrated at the intermagnet spaces and as these are located in the cryogenic system the gas we have to consider is helium.

First, assume a system with one pump at the end of each dewar (half cell) and consider each beam pipe separately.

*All pressures quoted in this note are the equivalent pressures at 293°K which corresponds to the same density of gas molecules unless specified otherwise.

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The conductance of the beam pipe is affected by temperature and at 4.5°K is for He:

$$C_{\text{He } 4.5^{\circ}\text{K}} = 3.8 \left(\frac{T}{M} \right)^{\frac{1}{2}} \frac{D^3}{L} = 1.6 \text{ l/sec for a 3 m length.}$$

The maximum allowable gas load Q at each point will be determined by the maximum ΔP we will allow in the system. In this case let us assume $a\Delta p = 10^{-10}$ torr or 3×10^6 molecules/cc. This pressure is equivalent to about 10^{-12} torr at 4.5°K.

$$\Delta P_{4.5^{\circ}\text{K}} = \frac{Q}{2C} + \frac{Q}{C} = \frac{3Q}{2C}$$

$$Q = \frac{2C \Delta P}{3} = \frac{3.2 \times 10^{-12}}{3} \approx \text{torr l/sec at } 4.5^{\circ}\text{K}$$

This is equivalent to 10^{-10} torr l/sec total leakage per intermagnet space, too small a number to be comfortable with, especially when one considers that some of the joints will see pressurized helium on the other side.

This exercise indicates that even at 4.5°K, pumps are needed at each intermagnet space. On this basis we can reconsider the problem as follows:

Having the means to pump at each intermagnet space we want to be able to keep the molecular density in the system $< 3 \times 10^6$ molecules/cc (10^{-10} torr) while assuming a total leak rate of 10^{-8} torr l/sec at each intermagnet space. Under these conditions, each intermagnet space can be considered individually hence:

$$\text{Pumping speed required } S = \frac{Q}{P} = \frac{10^{-8}}{10^{-10}} = 100 \text{ l/sec}$$

$$\text{Leak rate} = 3 \times 10^{11} \text{ molecules/sec } (10^{-8} \text{ torr l/sec})$$

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Conclusions:

It is evident from the above discussion that we can achieve an average pressure in ISABELLE of 10^{-10} torr and that this pressure can be obtained whether the vacuum chamber is at room temperature or cold. It is also clear that in the case of a room temperature beam pipe we need a vacuum pump at each intermagnet space whereas for the cold pipe a pump for each dewar (half cell would be sufficient.) However, this is only valid for a no-leak system. If we introduce the practical consideration that we have to be able to operate with leaks in the system, then both modus operandi require pumps at each intermagnet space and the pump size is predicated upon the leak rate we are willing to tolerate. In this note I have used 10^{-8} torr μ /sec as the maximum leak which will still allow to operate requiring a pumping speed of $\sim 100 \mu$ /sec per pump at 10^{-10} torr and 4.5°K or $\sim 130 \mu$ /sec per pump at 10^{-10} torr and 293°K.

Type of pumps available: There are very few vacuum pumps capable of achieving the low pressure we require ($<10^{-10}$ torr) and in addition, in the case of ISABELLE which will operate at 4.5°K, we can further state that:

- 1) after initial pump down, all residual gases with the exception of H_2 and He will be cryopumped on the vacuum chamber walls. Most potential leak paths will see helium on the pressure side. Hence we should not see a great increase of surface contamination due to condensable gases. Great care will be taken to limit this amount as these condensed gases will contribute to the "pressure bumps" produced by ion bombardment.
- 2) Hydrogen will not be present in a "cold machine" as it is mostly the outgassing product of diffusion from the beam pipe materials. Some however will be migrating in the cold areas from the room temperature regions.
- 3) Around most of the circumference of ISABELLE helium will be the predominant gas to be pumped because: a) having such a large cryogenic system present the partial pressure of He in the atmosphere is bound to be high and, b) most of the beam pipe will be surrounded by He (gas or liquid) on the pressure side, hence most leakage will be helium.

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It is then axiomatic that the vacuum pump chosen has to be designed to pump helium with a pumping speed of $\sim 100 \text{ l/sec}$ at 10^{-10} torr. Meeting this specification automatically means that all other gases will be pumped as well if not better than He since they are all easier to pump.

After review of available pumping techniques, two types of pumps stand out as possible candidates for the job:

- 1) the sputter ion pump which is well developed and has been used extensively at higher pressures. It is also used at the CERN ISR.
- 2) The cryosorption pump at liquid helium temperature. This pumping mechanism has been developed, however, it has had few applications so far because of the cost of helium refrigeration required. This technique is, I believe, the most promising approach to our problem.

Other pumping techniques, e.g., Orbion pumps, titanium sublimation, etc. are all rejected because of their inherent maintenance requirements and short life.

Ion pumping: Ion pumps will be used for all room temperature sections of ISABELLE including the beam transport from AGS. Despite their drawbacks and limitations they can be made effective at low pressures in conjunction with sublimation pumps, particularly when pumping hydrogen gas. At this time the pump we would choose would be the Varian triode 350 l/sec pump for which good experimental data is available. This pump is the one used at the CERN ISR. However, this pump is not necessarily the best choice for ISABELLE. Its characteristics and drawbacks are as follows:

- 1) The ultimate vacuum achievable after baking is $1-3 \times 10^{-11}$ torr under laboratory condition, (pumping speed = 0), and the pumping speeds for the pumps are very poor at low pressures. The 350 l/sec pump has a speed of 250 l/sec for air and 150 l/sec for hydrogen at 3×10^{-10} torr (See Fig. 1.)
- 2) Concurrently the pumping speed for helium is about 30% or less than that of air at the same pressure (Varian Associates Proposal 12/16/71.)

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- 3) Ion pumps are storage devices and eventually saturate. The saturation isotherm for helium and any other noble gas is only a fraction of the saturation for air, hence we have a life or total capacity limitation.^{1,2,3,4} Data on this effect is lacking and tests are needed to determine this limitation. Other cathode materials, (e.g. tantalum), have shown better affinity for helium and should be studied.^{5,6}
- 4) The pumping speed of ion pumps at low pressures can be enhanced with the addition of titanium sublimation. This technique as an adjunct to ion pumps at low pressure needs further development also as I am not aware of any qualitative data on this approach at this time.

Despite these limitations and drawbacks the ion pump is still the best choice available for all room temperature regions although cryosorption might well be competitive in these areas also.

Cryosorption pumping: Cryosorption is a practical means to achieve ultra-high vacuum of 10^{-10} torr or less,^{7,8} and in the case of ISABELLE the availability of liquid helium makes this technique economically interesting. However, at this time experience and experimental data is lacking in our area of interest and a program is required to evaluate the technique.

Cryosorption involves the physical adsorption of gases on solids at low temperature. Physical adsorption has been studied for many years. Brunauer⁹ gives a good review on this work. In 1947 Dubinin and Radushkevich¹⁰ working on the adsorption of gas on activated charcoal proposed the isotherm equation

$$\ln \theta = - B \epsilon^2$$

where θ = relative surface coverage on adsorbent

B = constant for given gas

ϵ = Polanyi potential term⁹

$$\epsilon = \int_{P_x}^{P_0} RT \, dP = RT \int_{P_x}^{P_0} \frac{P}{P_0} \, dP$$

where R = gas constant

T = temperature °K

P = pressure

P_0 = vapor pressure at T

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The Polanyi potential theory predicts that a characteristic curve independent of temperature is obtained when the coverage is plotted as a function of the potential ϵ . Also the theory states that for the adsorption of gases near their boiling points, the adsorption areas with adsorption energies $E \geq \epsilon$ are the only ones contributing to adsorption. The distribution of values of E on the surface will therefore determine the form of the potential curve and this form might be expected to vary with different adsorbate - adsorbent combinations.

Hobson ¹¹ describes the adsorbent surface by a distribution of adsorption energies

$$f(E) = \frac{2E}{E_m^2} \exp \left(\frac{-E}{E_m} \right)^2$$

If the distribution function is then postulated where $f(E)$ is the fraction of the surface with energy between E and $E + dE$ and E_m is the mean energy of adsorption, then the Dubinin-Radushkevich equation is obtained when the assumption of potential theory is applied:

$$\begin{aligned} \theta &= \int_{-RT \ln \frac{P}{P_0}}^{\infty} \frac{2E}{E_m^2} \exp \left(\frac{-E}{E_m} \right)^2 dE \\ &= \exp \left(\frac{-RT \ln \left(\frac{P}{P_0} \right)}{E_m} \right)^2 \\ &= \exp - \frac{1}{E_m^2} \epsilon^2 \quad \text{where } \epsilon = -RT \ln \left(\frac{P}{P_0} \right) \\ &= \exp - B \epsilon^2 \quad \text{where } B = \frac{1}{E_m^2} \end{aligned}$$

The Dubinin-Radushkevich equation has been applied extensively to adsorption on activated charcoal and matched reliably the experimental results at "high" pressures $P > 10^{-5}$ torr.

In the last 10 years experimental adsorption isotherms in the pressure ranges $P > 10^{-10}$ torr have been measured for He, H₂, Ar, N₂, CH₄, Kr and Xe on various adsorbents^{11,12,13,14,15,16}. All the adsorption isotherms measured have shown: the temperature dependence predicated by the Polanyi potential theory⁹, i.e. $\theta = f(\epsilon)$, each isotherm measured can be described by the

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Dubinin-Radushkevich equation $\theta = \exp -B\epsilon^2$ and, no data has shown Henry's law⁷ dependence for the relative coverage upon pressure, i.e. $\theta \propto Kp$.

On the basis of the experimental data available, Hobson^{17,18,19} has developed a more accurate model fitting the experimental adsorption isotherms taking into account in addition, the distribution of adsorption energies E related to the gas considered and the intermolecular forces Q of the adsorbate. This is particularly important for gases which can have large Q . Q will vary from 0 to a maximum equal to the heat of liquefaction of the gas. $Q_{\max}$ for helium is very small (~ 23 cal/mole) hence can be neglected. Redhead, Hobson and Kornelsen²⁰ give a very good review of this work to date.

The Linde Division of Union Carbide Corp. under contract to the Air Force has developed a cryosorption pump using a molecular sieve material (synthetic zeolite type 5A) for which data was obtained on the adsorption isotherm for helium at 4.2°K ^{14,21}. This data however does not extend below 10^{-8} torr. Using the isotherm equation given above we can extrapolate the data to lower pressures. Taking values for helium at 4.5°K from Hobson¹¹ where $B = 4 \times 10^{-5}$ ($E_m = 158$ cal/mole) and $P_0 = 760$ torr we can calculate the isotherm of helium on zeolite 5A from the available data. The results obtained are shown on Figures 2 and 2A. The definition of θ which for normal surface adsorbents is given as the fraction of one monomolecular layer surface coverage does not hold for zeolite. In this case it is given as a fraction of saturated gas volume (cm^3 STP) per unit weight of adsorbent.

The calculated isotherm for zeolite fits the experimental data obtained. The displacement of the curve is due to the definition of saturation or full coverage. It is to be noted however that the experimental data does not cover pressures $< 5 \times 10^{-8}$ torr. Experiments are therefore required to confirm the isotherm in the ultra-high vacuum region.

Figure 3 contains additional data received from Linde Div. of Union Carbide Corp. pertaining to the sticking coefficient for helium on their material and it indicates the following:

- 1) The sticking coefficient for helium on molecular sieve 5A at 4.2°K is ~ 1 up to 10% saturation, then drops rapidly to ~ 0.1 at 40% saturation.

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- 2) The sticking coefficient is temperature dependent and drops from about 1 at 4.2°K to 0.1 at 5°K.

This data is quantitative and needs to be refined further experimentally.

On the basis of the information available on cryosorption pumping we can design a system around the following parameters:

- 1) sticking coefficient = 0.1
- 2) maximum pump capacity = 10% of saturation
- 3) each pump to operate for one year pumping on a 10^{-8} torr μ /sec leak, this is equal to a total pumping capacity of 10^{19} molecules at 10% saturation for one year.

Using Linde's molecular sieve 5A as adsorbent for the pumps and taking 10% of the calculated isotherm at 4.5°K as total capacity, we can adsorb at 10^{-10} torr about 1 cm³ (STP) of gas per gram of adsorbent. 1 cm³ (STP) contains about 10^{19} molecules so that 1 gram of adsorbent per pump should theoretically be sufficient (if 100% efficient) to operate for 1 year at 10^{-10} with a 10^{-8} torr μ /sec leak.

As designed by Linde the adsorbent is bonded to a metallic substrate providing good heat transfer. About one gram of adsorbent is applied to 10 cm² of surface area.

Now if we apply the sticking coefficient, s , to the surface area, we can determine the area of adsorbent required to maintain the system at 10^{-10} torr with a leak Q , of 10^{-8} torr μ /sec. (3.3×10^{11} mol/sec)

$$A = \frac{Q}{vs}$$

where v = number of molecules impinging on the surface per sec

$$v \text{ at } 10^{-10} \text{ torr} = \frac{n}{4} \frac{8kT}{\pi m}^{\frac{1}{2}} = P(2\pi mkT)^{-\frac{1}{2}} = 10^{10} \text{ mol/sec-cm}^2$$

$$\text{hence } A = \frac{3.3 \times 10^{11}}{0.1 \times 10^{10}} = 330 \text{ cm}^2$$

This is a panel 7.5 x 7.5 in. or a cylinder 6-in. dia. 3-in high which seems reasonable. This exercise shows that, even remaining very conservative, if the Linde cryosorption pump lives up to expectation, it is a practical and economical means of achieving the average pressure of 10^{-10} torr that we specified. On that basis this pumping technique is the one proposed for ISABELLE.

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The cryosorption pumps proposed for the job will consist of two types (Fig. 4):

- 1) Cryosorption pumps which in addition to the adsorbent will have a cryo-cooled chevron baffle.
- 2) Cryosorption panels consisting only of adsorbent panels built in the vacuum chamber system.

The proposal for two types of pumps is predicated by the need to avoid contamination of heavier condensable gases on the adsorbent. This is accomplished by having the pumps at the interdewar space (where space is available) preceded by a cryogenic baffle which will cryopump all condensable gases like O_2 , N_2 , CO_2 , Ar, etc. These pumps will therefore be cooled down while the beam pipe is still at room temperature, thus needing a different cooling circuit; the cryosorption panels will be cooled in series with the beam pipe.

General System Layout:

Based upon the preceding discussion, it is proposed that ISABELLE have the following characteristics:

- 1) All beam pipes will be cooled to $4.5^{\circ}K$ excluding only the areas where cooling would be detrimental to operation. This feature will provide the ability to bake as well using $300^{\circ}C$ gas.
- 2) A cryosorption panel will be located at each intermagnet space in the dewar and will be cooled in series with the beam pipe.
- 3) A cryosorption pump will be located at each half cell (1 m space) in the dewar vacuum vessel to take advantage of a common insulation system. A separate cooling circuit will be used to cool the cryosorption pumps prior to cooling the beam pipes and panels.
- 4) Ion pumps will be used for the room temperature regions in conjunction with titanium sublimation pumps and cryosorption pumps. This area needs development as the pressures required in the interaction regions need to be much lower than the 10^{-10} torr contemplated so far.

Figure 5 shows a typical half cell (dewar unit) containing one cryosorption pump and 6 cryosorption panels. Figure 6 shows schematically a quadrant of ISABELLE with a typical pump distribution round the ring. The entire vacuum system for the machine will operate at cryogenic temperature with the exception of the interaction region shown by a heavy line on Fig. 6.

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Sector valves are provided around the circumference of the rings to allow the isolation of a section for changes and repair. Although it is desirable to make an isolated section as short as possible to avoid unnecessary contamination and thermal cycling of the beam pipe when baking, the cost and complexity of these valves tend to limit their number. Forty-two sector valves are planned for each ring providing isolation for the interaction regions, the long and short straight sections and each pair of cells (4 dewars) of the bending sections. The longest section open to atmosphere in case of a breakdown would then be about 60 meters. Also, since the vacuum system of both rings will be connected this length applies to both beam pipes and each pair of sector valves will be made to operate simultaneously. The sector valve design is critical, the requirement is for an all-metal gate valve with a very low leak rate $<10^{-9}$ torr ℓ /sec bakeable in the closed position. This valve is not available commercially and will have to be developed.

Operation:

Although no attempt has been made so far to analyze the pump-down cycle, Fig. 7 shows quantitatively what we can expect as pumped down time for a typical section. A conservative estimate of this time is 40 to 48 hours.

The pump down time is affected mainly by two factors:

- 1) Required bakeout time: so far the statement that we have to bake at 300°C for 24 hours has been an educated guess based on other peoples experience and on what seems practical. We do not know yet qualitatively what constitutes "clean walls" in terms of gas desorption due to ion bombardment and much work is required in this area to determine the baking requirement. Since the beam pipe will ultimately be cooled to 4.5°K the diffusion problem does not exist practically so that the bake will entirely be predicated by the beam-induced gas desorption problem.
- 2) Ultimate pressure with beam pipe at room temperature: because of the same effect outlined above, most condensable gases should be removed from the beam pipe prior to the pipe cooldown. This will be accomplished by activating the cryosorption pumps and operating these for a length of time prior to cooling down the pipe to 4.5°K . An estimate of the residual condensable gases

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With time can be made using a Monte-Carlo calculation when we have a physical design for the system.

These two factors constitute about 70% of the pump downtime. The rest is the result of volumes, outgassing rates, leaks, conductances, etc., and are relatively less controllable.

Conclusions:

This note provides the basis for an approach to achieve the vacuum quality required for ISABELLE. I am confident that such a system can be made to meet our specifications and to operate reliably. However, it is evident that much work is required, both theoretical and experimental, to arrive at the final solution. Cryosorption pumping has never been used for these very low pressures and on such a scale, but I believe that it will prove to be practical and that it will be lower in cost than an equivalent ion pumping system by a factor of 2 to 3.

PG/hm

Distribution: CRISP

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Fig # 1

Fig # 2

Fig # 2A

FIG # 3

CRYOSORPTION PUMP
(INTERDEWAR SPACE)
NO SCALE

CRYOSORPTION PANEL
(INTER-MAGNET SPACE)
NO SCALE

FIG 4

FIG. 5

Fig. 6 ISABELLE Vacuum System Schematic

TIME (HOURS)

Fig # 7