New Folder Name Water Outgassing

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NOTES:

VIEWGRAPHS AND ABSTRACT FOR PRESENTATION AT NIST WORKSHOP ON WATER IN VACUUM SYSTEMS

MAY 23, 24 1994

FRED DYLLA IS RESPONSIBLE FOR THIS WORKSHOP

Water Outgassing Data and Model for the LIGO Beam Tubes *

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The Laser Interferometer Gravitational-wave Observatory (LIGO) is a joint project of Caltech and MIT sponsored by the NSF to detect gravitational waves from astrophysical sources by laser interferometry. Gravitational waves induce strains in space sensed by measuring the relative motions of four suspended test masses placed near the vertex and at the ends of a vacuum system in the shape of an L. The arms of the L, the beam tubes, are 4 km long with a diameter of 124 cm. The tubes need to be evacuated so that molecular column density fluctuations of the residual gas (index of refraction fluctuations) do not compromise the measurements. Initial interferometers with a strain sensitivity $\approx 10^{-22}$ require an average pressure of $\leq 10^{-6}$ torr H_2 and $\leq 10^{-7}$ torr H_2O. The LIGO facilities are designed to accomodate improved detectors requiring pressures 10^{-3} times lower.

The vacuum challenge for the project is to design, construct and evacuate the beam tubes economically. The beam tubes being planned are spiral welded 304L stainless steel with 3.2 mm wall thickness stiffened by rings spaced at 76 cm intervals. The steel is baked in air for 36 hours at 440 C to reduce the hydrogen outgassing to $\leq 10^{-13}$ torr liters/sec cm^2. The air bake leaves a 500 ± 200 Angstrom oxide coating on the surface. The oxide serves to attenuate stray light in the tubes. To reduce the water outgassing, the tubes and associated expansion joints are insulated and baked under vacuum at 140C for 1 month. The bake is carried out by using the tubes themselves as resistive heaters.

The water outgassing measured in a test system 61 cm in diameter 40 meters long was $4.0 \times 10^{-8}/t(\text{hours})$ torr liters/sec cm^2 at 300K before the bake and 1.1×10^{-16} torr liters/sec cm^2 after the bake.

A heuristic classical statistical mechanics model has been fit to the water outgassing data. The model uses Langmuir adsorption theory with the Dubinin and Radushkevich distribution of adsorption site binding energies and a repulsive surface potential proportional in magnitude to the binding energy to account for readsorption. The model has been incorporated into a computer code that performs a detailed balance calculation for 1000 adsorption site energies.

The model parameters are determined from the outgassing data. The ratio of the initial surface loading to the average binding energy is estimated from the intial pumpdown data. The average binding energy is determined from outgassing rate derivatives with temperature during the bake while the amplitude of the repulsive potential is estimated from the readsorption after cooldown from the bake.

The water outgassing data from the test system is fit by an initial surface loading of 280 monolayers, an average binding energy of 10000 K, and a repulsive potential 0.7 times the binding energy of a site. The accomodation coefficient is set at 0.5. The final surface loading after bake is 11 monolayers.

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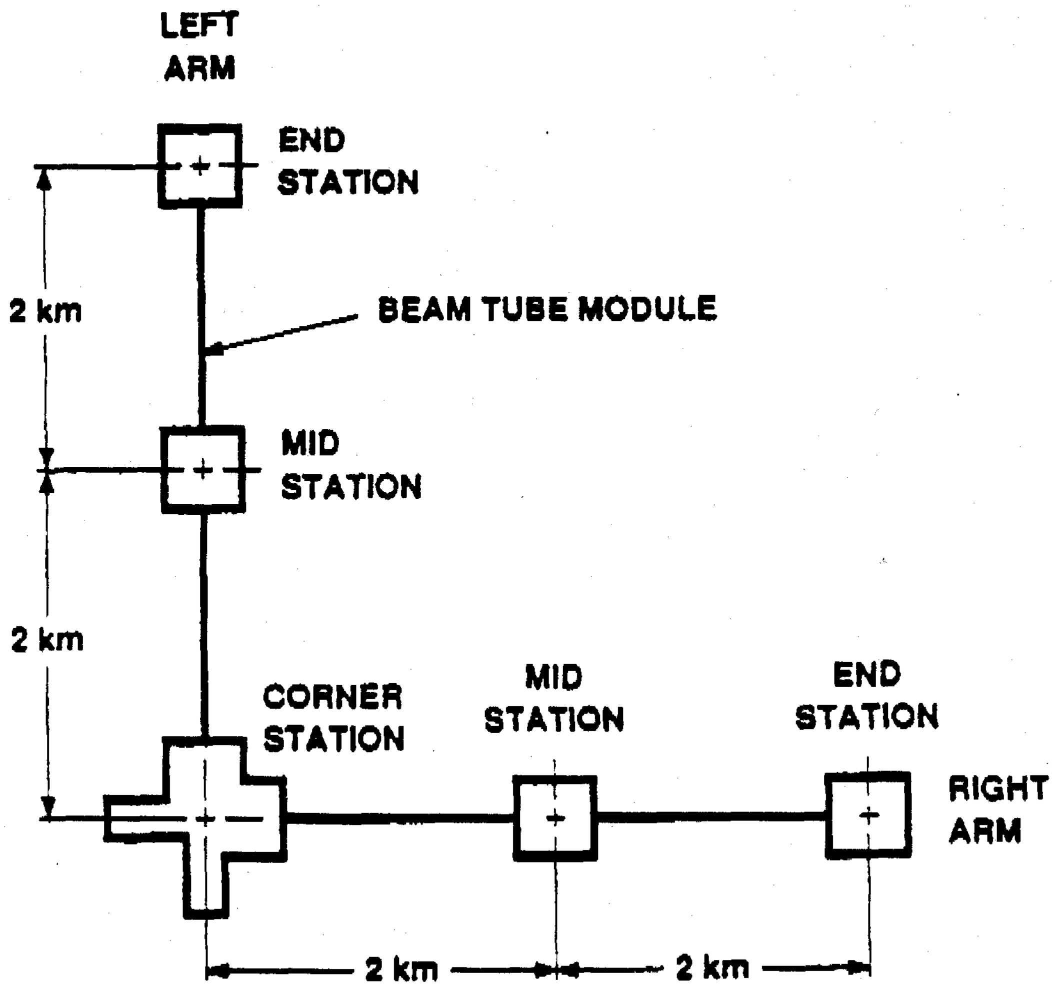
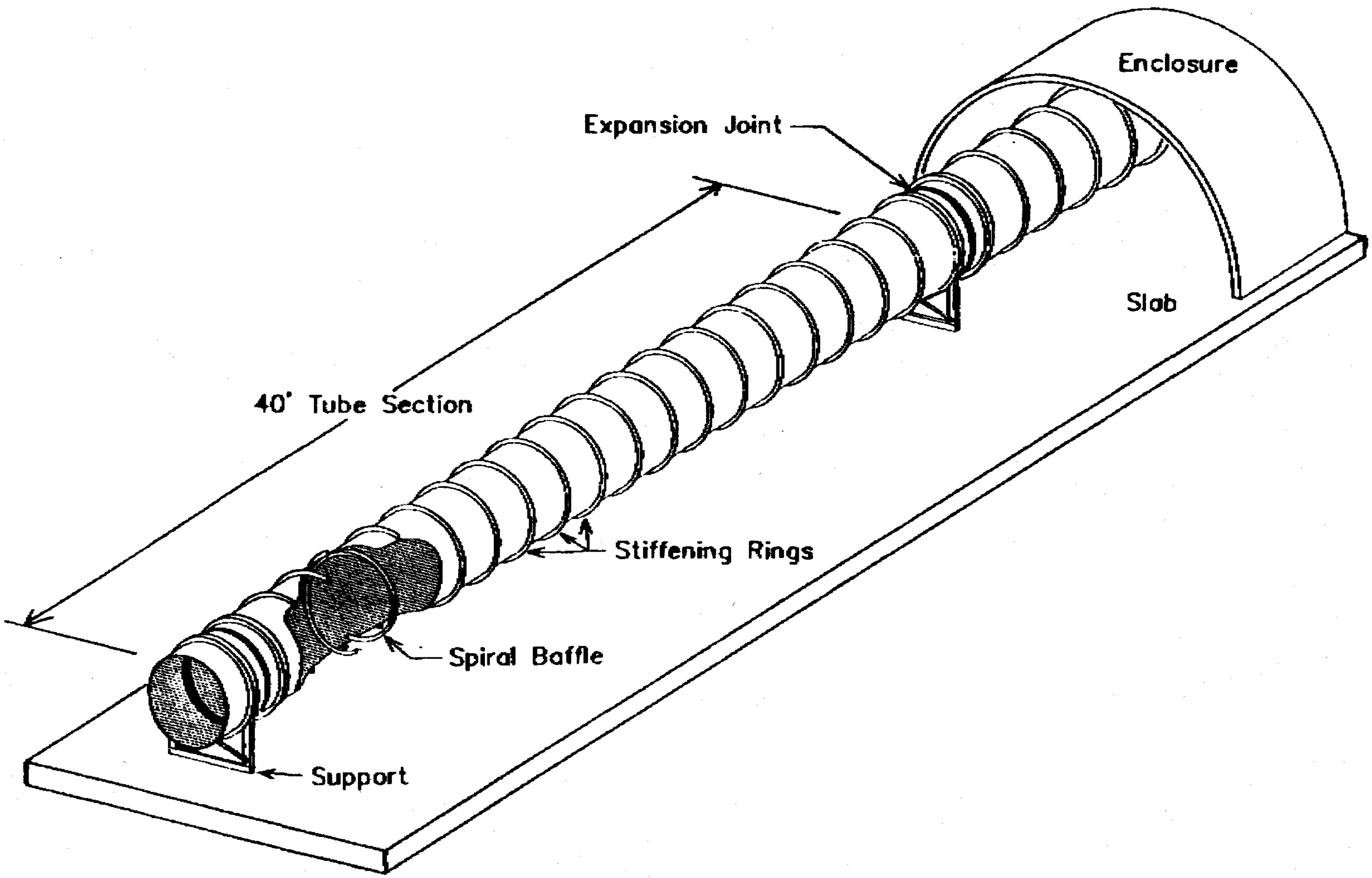

LEFT
ARM
END
STATION
2 km
BEAM TUBE MODULE
MID
STATION
2 km
CORNER
STATION
MID
STATION
END
STATION
RIGHT
ARM
2 km
2 km


Enclosure
Expansion Joint
Slab
40' Tube Section
Stiffening Rings
Spiral Baffle
Support

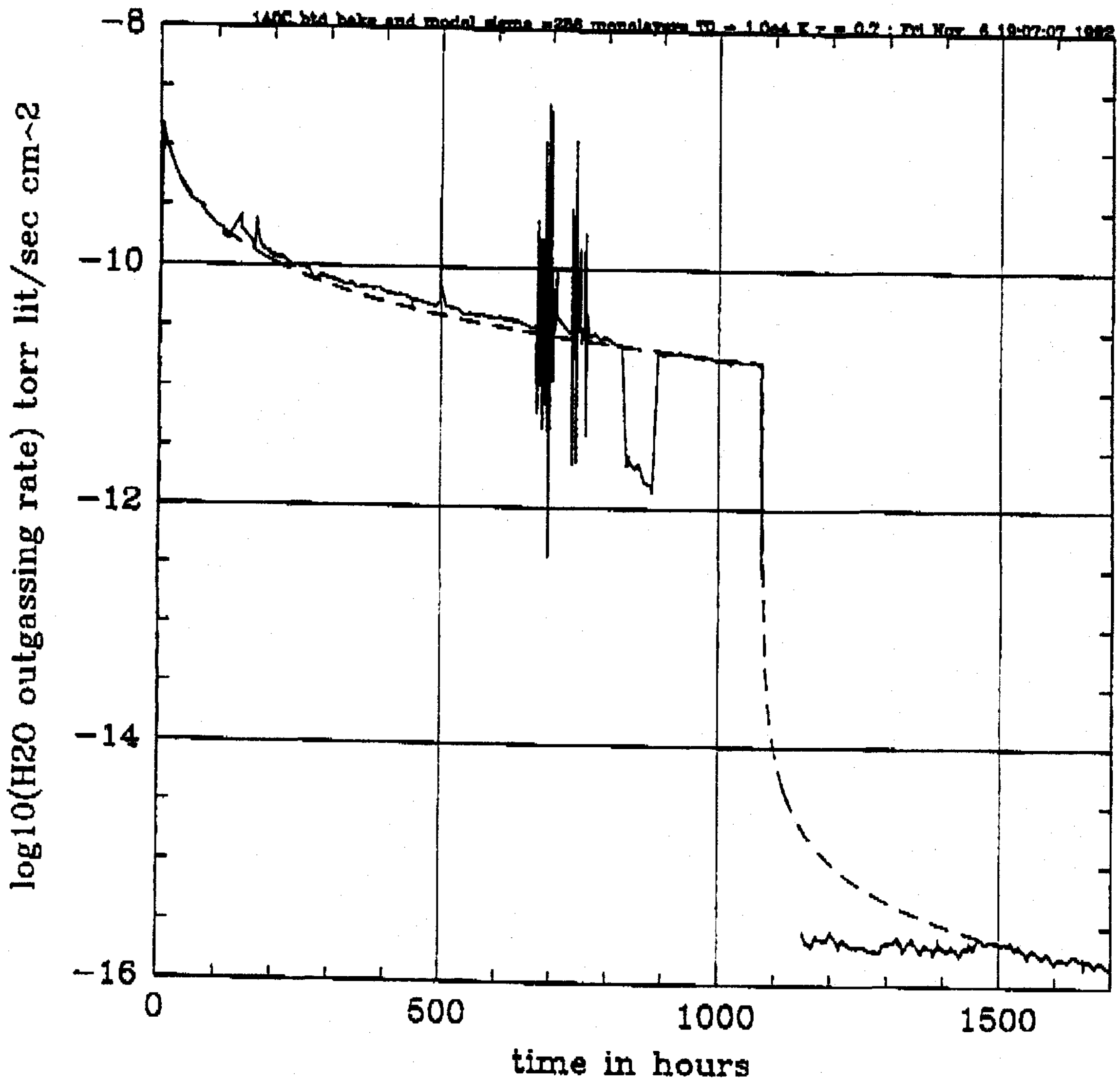

-8
-10
-12
-14
-16
log10(H2O outgassing rate) torr lit/sec cm^-2
0
500
1000
1500
time in hours

FIG 7

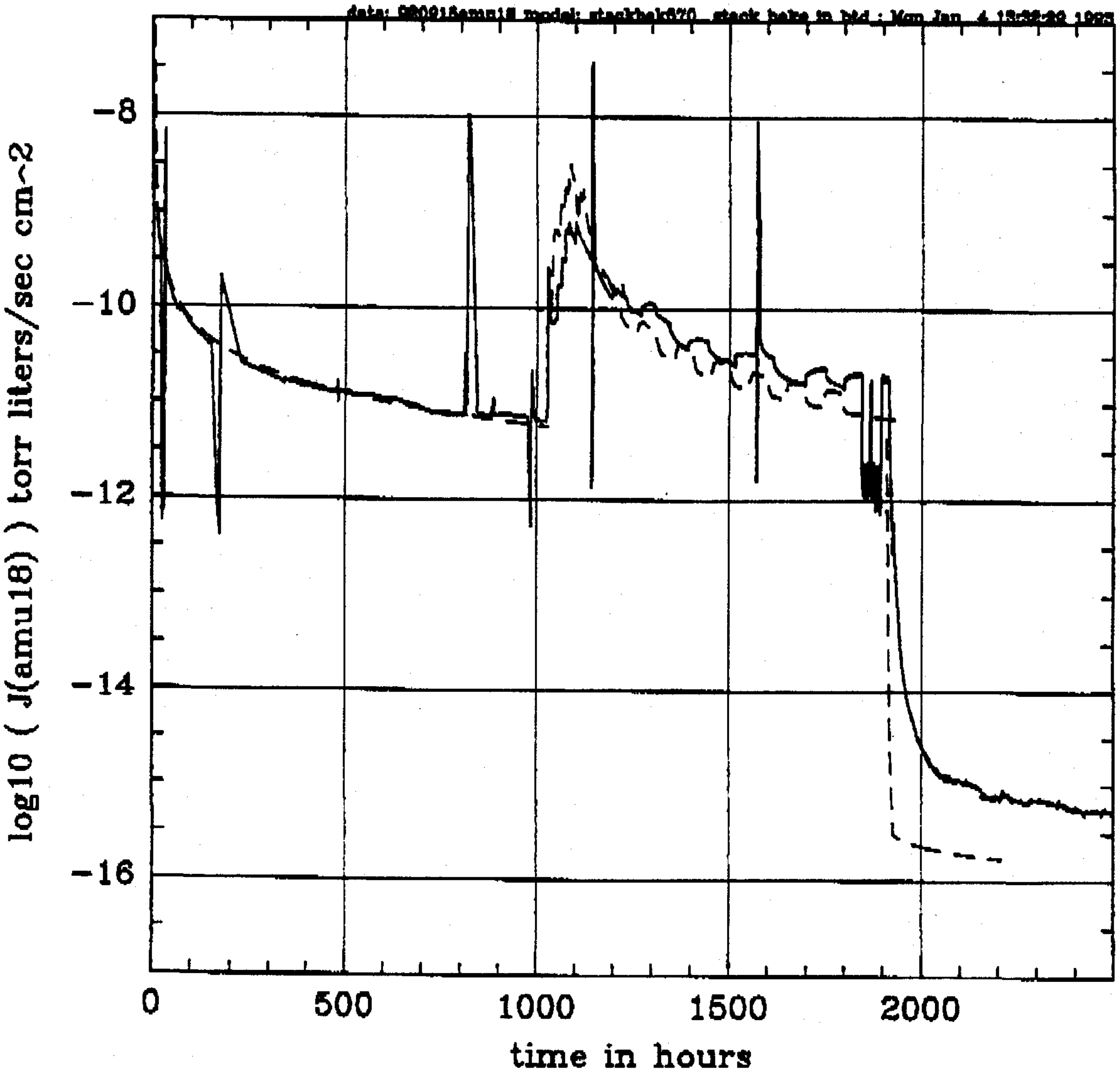

-8
-10
-12
-14
-16
log10 (J(amu18)) torr liters/sec cm^-2
0
500
1000
1500
2000
time in hours

FIG 8

Heuristic Statistical Mechanics Model

Dubinin-Radushkevich (DR) equilibrium surface coverage:

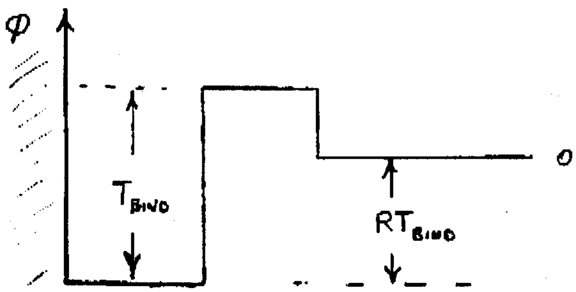
$$\frac{\sigma}{\sigma_m} = e^{-(T/T_0)^2 ln^2(P/P_0)}$$

DR site distribution function:

$$\theta(T_{bind}) = \left(2T_{bind}/{T_0}^2\right) e^{-(T_{bind}/T_0)^2}$$

$$\int_0^\infty \theta(T_{bind}) \delta T_{bind} = 1$$

Heuristic surface potential:



Emission time:

$$\tau_{emit}(T_{bind}) = \tau_0 e^{T_{bind}/T}$$

Adsorption time:

$$\tau_{ads} = \frac{4n\sigma_0}{\alpha\rho v_{th}(1 + (1-R)T_{bind}/T)e^{-(1-R)T_{bind}/T}}$$

Detailed balance per site:

$$\frac{dP(T_{bind}, t)}{dt} = -\frac{P(T_{bind}, t)}{\tau_{emit}} + \frac{(1 - P(T_{bind}, t))}{\tau_{ads}}$$

Integration:

$$P(T_{bind},t) \;=\; P(T_{bind},0)e^{-t/\tau} \;+\; P_{equil}(T_{bind})(1 \;-\; e^{-t/\tau})$$

where

$$\tau = \frac{\tau_{emit}\tau_{ads}}{(\tau_{emit} \;+\; \tau_{ads})}$$

and

$$P_{equil}(T_{bind}) \;=\; \frac{\tau_{emit}}{(\tau_{emit} \;+\; \tau_{ads})}.$$

Incremental outgassing rate of band of sites:

$$dJ_{out}(t) = n\sigma_0\;\theta(T_{bind})(\frac{dP(T_{bind},t)}{dt})\;\delta T_{bind}$$

Aside: for $P(T_{bind},0) \;=\; 1$ and $\tau_{ads} \rightarrow \infty$

$$J_{out}(t,T) = \left(\frac{2n\sigma_0 T}{tT_0}\right)\int_0^a bln(y/a)e^{-(bln(y/a))^2}e^{-y}dy$$

where

$$b = T/T_0 \qquad a = t/\tau_0$$

Computational algorithm (waterbakesm.f)

Step time:

$$\Delta t/\tau_s = f \quad \tau_s = V/F$$

Probability computation over 1024 binding energies $0 \rightarrow 3T_0$

$$P(T_{bind}, t_{j+1}) = P(T_{bind}, t_j)\, e^{-f\tau_s/\tau_j} + P_{equil}(T_{bind}, t_j)\,(1 - e^{-f\tau_s/\tau_j})$$

Surface coverage:

$$\sigma(t_{j+1}) = n\sigma_0 \sum_{0}^{3T_0} \theta(T_{bind}) P(T_{bind}, t_{j+1}).$$

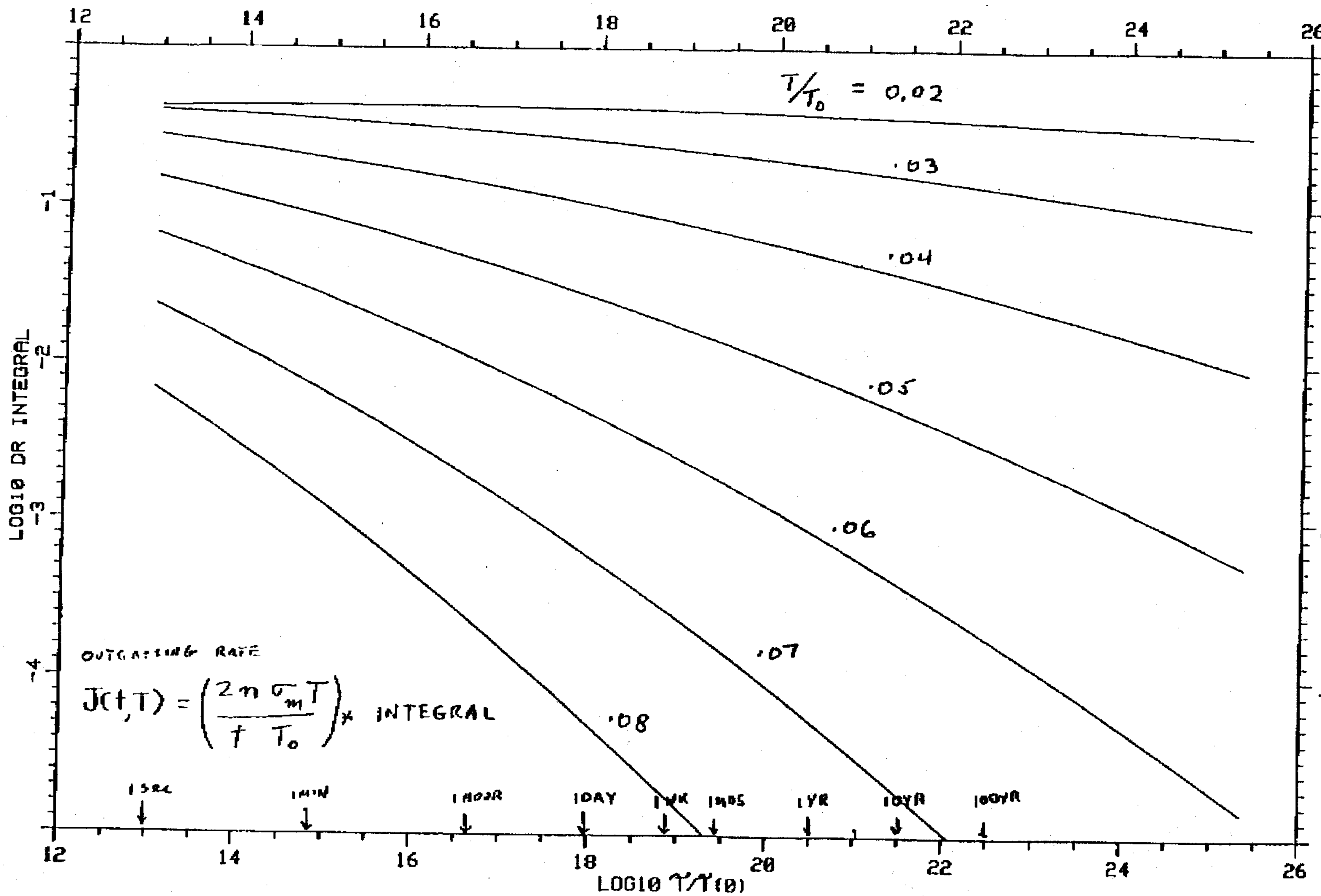
Outgassing rate:

$$J(t_{j+1}) = \frac{(\sigma(t_{j+1}) - \sigma(t_j))}{f\tau_s}$$

Pressure:

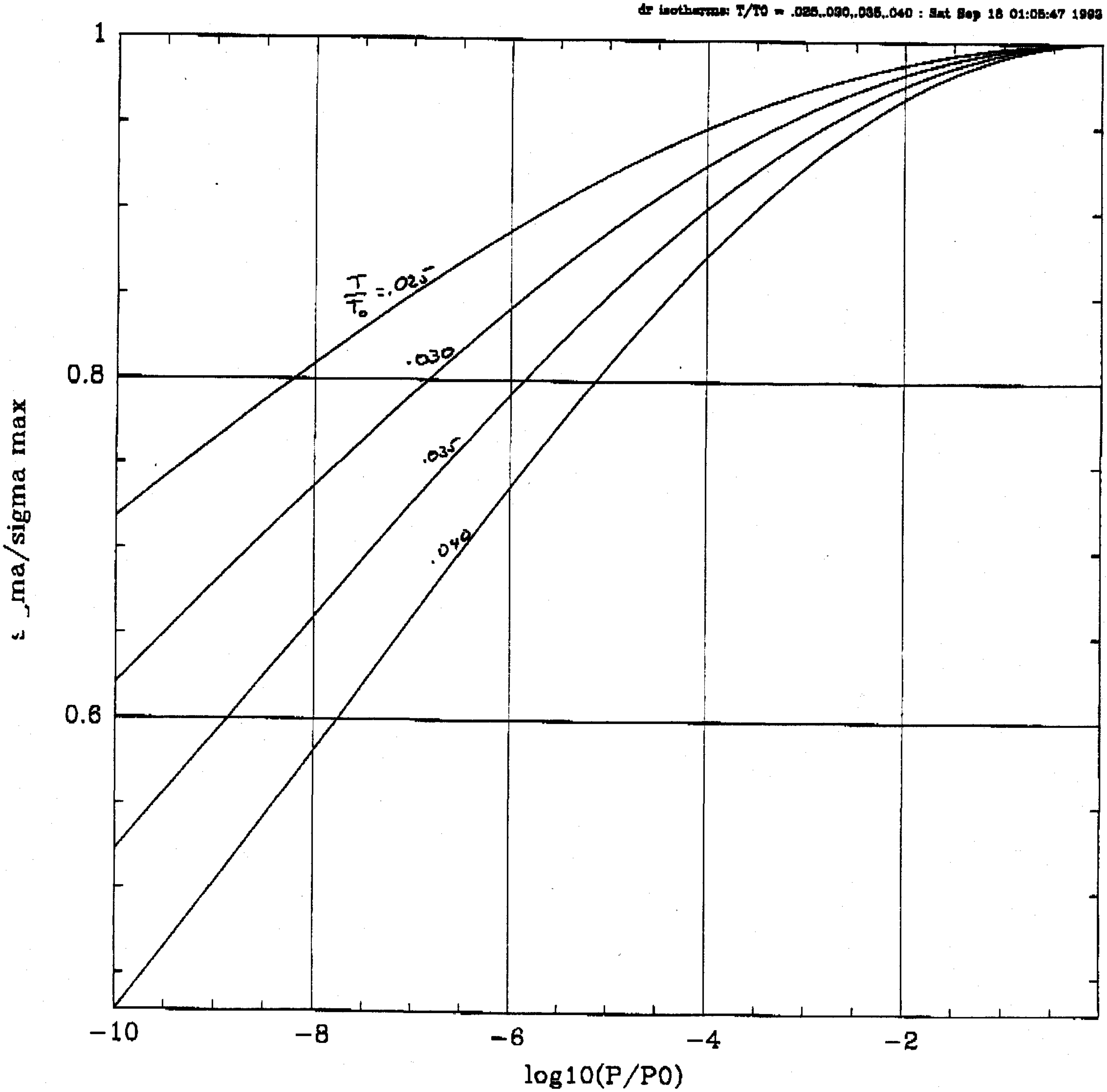
$$p(t_{j+1}) = p(t_j)\, e^{-f} + (\frac{J(t_j)A}{F})(1 - e^{-f})$$

GO BACK AND DO IT AGAIN (new time and temperatures)



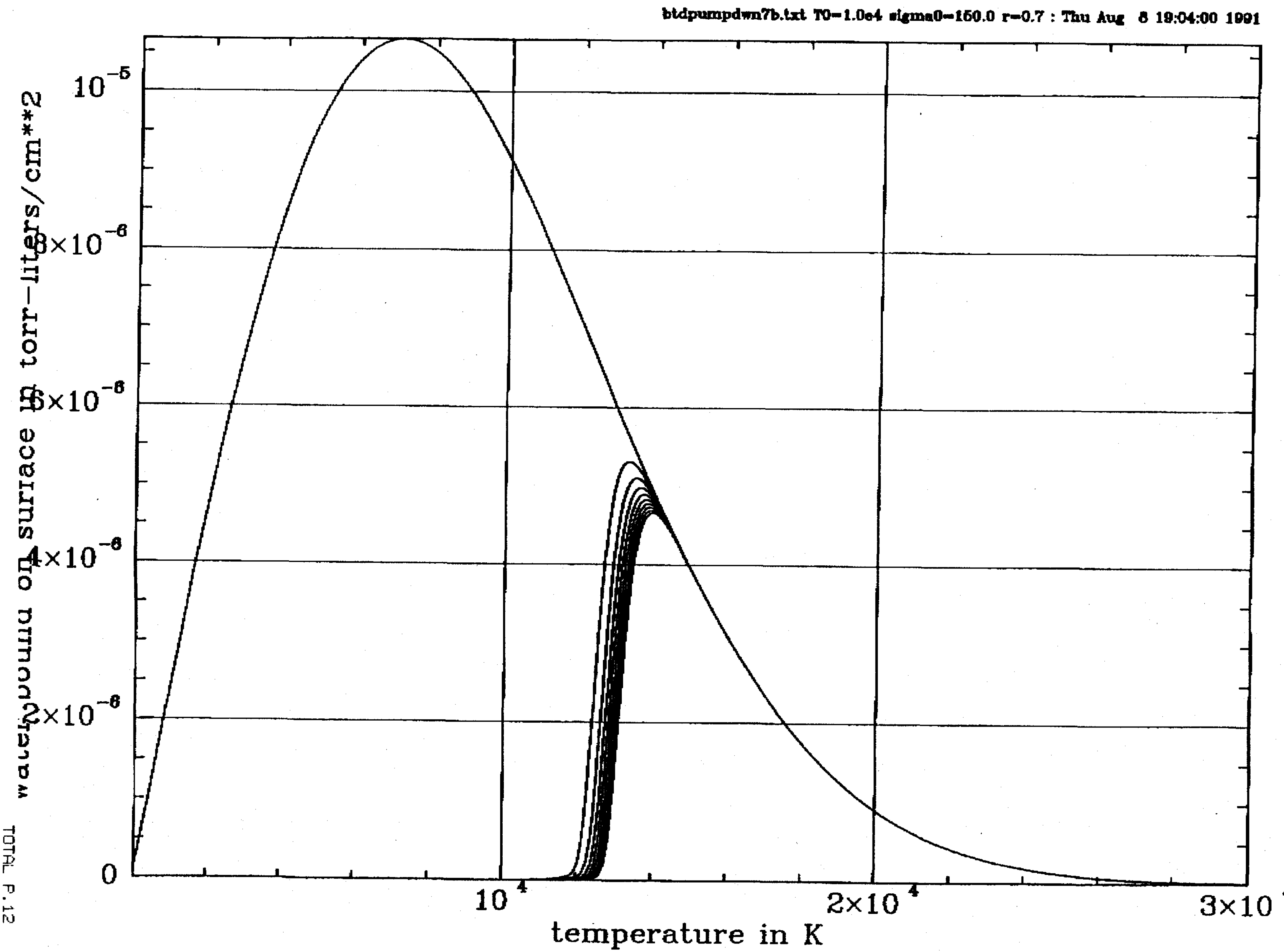
DR INTEGRAL VS NORMALIZED PUMPING TIME

Assume $\tau_0 = 10^{-13}$ sec



$$\frac{\sigma}{\sigma_m} = e^{-\left(\frac{T}{T_0}\right)^2 \ln^2\left(P/P_0\right)}$$

EQUILIBRIUM WITH SURFACE


btdpumpdwn7b.txt T0=1.0e4 sigma0=150.0 r=0.7 : Thu Aug 8 19:04:00 1991
water bound on surface in torr-liters/cm**2
10^{-5}
8×10^{-6}
6×10^{-6}
4×10^{-6}
2×10^{-6}
0
10^{4}
2×10^{4}
3×10^{4}
temperature in K