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CRYOGENIC LIQUID SPILLAGE IN A LEP EXPERIMENTAL AREA

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INTRODUCTION

In this note we analyse possible hazards as a consequence of large quantities of cryogenic liquid leaking into experimental zones of LEP.

This analysis leads to conclusions and suggestions about how to cope with these potential dangers.

Of the planned LEP experiments we have chosen "DELPHI" as exemple, since the volume of cryogenic fluids is the most important.

BASIC PARAMETERS AS KNOWN TO DATE

DELPHI (fig. 1)

	Fluide	Volume m ³	Op. Temp °K	Op. press. bar
Barrel e.m. cal.	Liq. Argon	20	87	2
Forward e.m. cal.	Liq. Argon	8 x 2	87	2

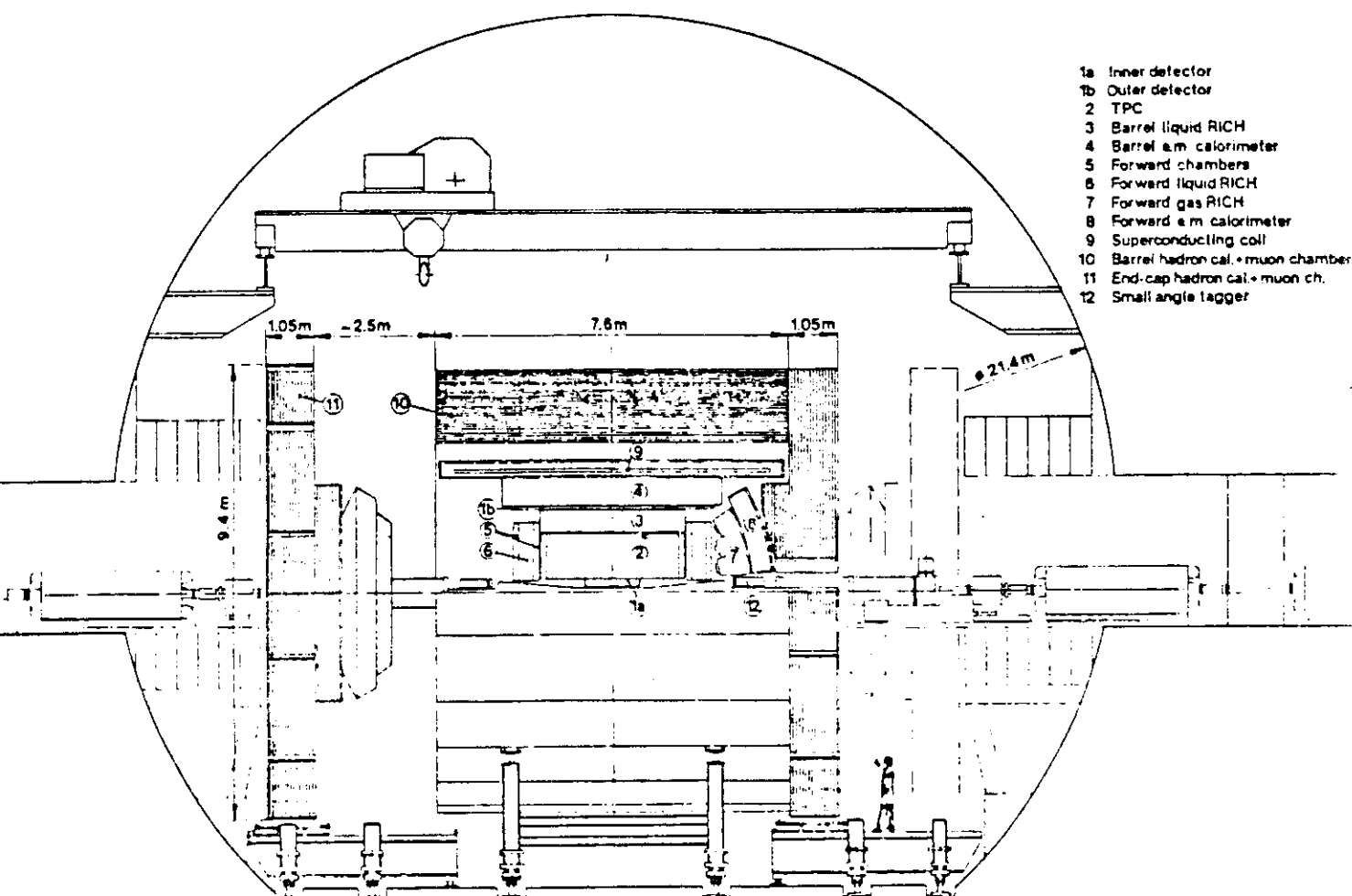
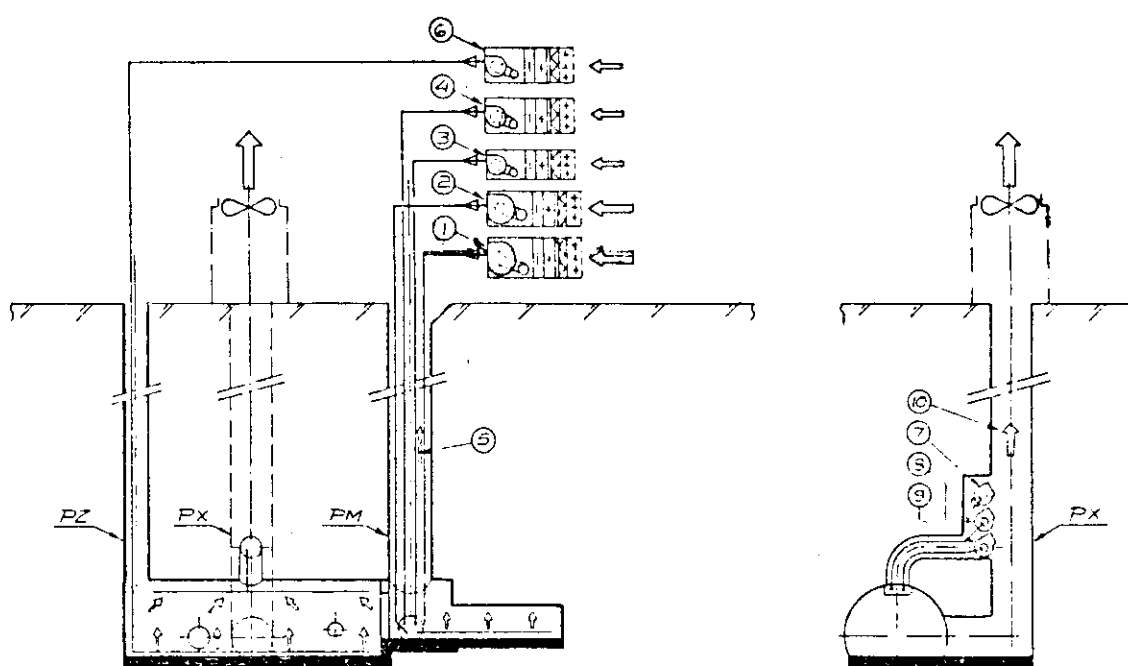


Fig. 1 : DELPHI

VENTILATION SYSTEM (fig. 2)

"Petite Vitesse"	P.V.	=	20.000 Nm ³ /h	=	5.5 Nm ³ /s
"Grande Vitesse"	G.V.	=	40.000 Nm ³ /h	=	11.1 Nm ³ /s
"Très Grande Vitesse"	T.G.V.	=	88.000 Nm ³ /h	=	24.4 Nm ³ /s
"Detector local extraction"	D.E.	=	5.000 x 2 Nm ³ /h	=	1.4 x 2 Nm ³ /s

P.V., G.V. and T.G.V. flows include the D.E. flow.



- | | |
|---------------------------------|---------------------------------------|
| ① 16000/32000 m ³ /h | ⑥ 20000/40000 m ³ /h |
| ② 16000/32000 m ³ /h | ⑦ 20000/40000 m ³ /h |
| ③ 8000 m ³ /h | ⑧ 5000 m ³ /h |
| ④ 8000 m ³ /h | ⑨ 5000 m ³ /h |
| ⑤ 16000 m ³ /h | ⑩ 20000/40000/88000 m ³ /h |

fig. 2 : the scheme of the ventilation system for the underground experimental areas.

EXPERIMENTAL AREA

Volume $V \approx 20,000 \text{ m}^3$
Floor surface area $S \approx 1,700 \text{ m}^2$

Concrete floor characteristics (assumed values) :

- Density $\rho = 1.600 \text{ kg/m}^3$
- Specific heat $c = 0.21 \text{ kcal/Kg.}^\circ\text{K}$
- Thermal conductivity $\lambda = 0.72 \text{ Kcal/m.h.}^\circ\text{K}$
- Thermal diffusivity $\chi = 0.595 \cdot 10^{-6} \text{ m}^2/\text{s}$
- Ambient temperature $t_o = 300^\circ\text{K}$

THERMODYNAMIC BEHAVIOUR OF THE SYSTEM

Let's first try to understand what would happen if a quantity of liquid Argon is spilled over a flat surface of concrete.

In a simplified approach we neglect the influence of the apparatus surface and the ambient air in contact with the spilled Argon.

Then, all the heat of evaporation has to be taken out of the floor (concrete) and the following dependence (Fourier law) describes the phenomenon (ref. 1, 2).

$$\frac{\partial^2 t}{\partial x^2} = \frac{1}{\chi} \frac{\partial t}{\partial \tau} \quad (1)$$

where :

t is the temperature $t = t(x, \tau)$

x is the distance from the surface into the concrete

τ is the time parameter

χ is the thermal diffusivity $\chi = k/\rho.c$

Eq.(1) applied to the concrete of the floor, as a homogeneous semi-infinite body, is subject to the following boundary conditions :

$$t_o = 300^\circ \text{K}$$

$$t_l = 87.5^\circ \text{K} \quad \text{at } \tau = 0 \quad (2)$$

Eq.(1) is solved using an approximate analytical method (see appendix, ref. 3) giving :

$t = t(x, \tau)$	The temperature in the concrete as a function of the parameters x and τ ;
$\delta = \delta(\tau)$	the penetration depth of the thermal perturbation at time τ ;
$Q = Q(\delta)$	the heat loss in the ground for a penetration δ , at a given time τ .

Finally we can calculate the mass of Argon evaporated (W_A) corresponding to Q , and the volume (V_A) of the vapour produced, per square meter of floor, at any time after the spillage.

Table 1 shows the results of these calculations :

τ sec	δ mm	Q Kcal / m ²	W_A Kg / m ²	V_A m ³ / m ²
5	5.8	138	3.55	0.602
10	8.2	195	5.02	0.851
30	14.2	338	8.69	1.474
45	17.4	414	10.64	1.805
60	20.1	478	12.69	2.085
90	24.6	586	15.06	2.555
100	25.9	617	15.87	2.691

Table 1 : vapour of Argon produced per m² as function of τ .

Values of V_A in m³/m² represent also the depth of the vapour on the floor. After $\tau = 100$ sec , 27.000 kg are evaporated on a surface $S = 1700$ m², i.e. about 20 m³ of liquid, corresponding to the volume of the barrel calorimeter.

These calculations are corroborated by some tests made at CERN (ref, 4), giving $Q = 450$ Kcal/m².min for the liquid nitrogen.

The cold Argon gas behaves like a liquid for quite some time and stays at the bottom (thermal stratification). Diffusion into the air is slow and aided essentially by thermal turbulences (ref. 5).

PRACTICAL CONSEQUENCES

From tab. 1, the heat quantity available from the concrete floor is sufficient to evaporate about 20 m^3 of liquid Argon within about 100 sec, enough to fill the whole experimental hall up to 2.7 m from the floor level, neglecting the volumes of the equipment installed.

However the level attained at $\tau = 10 \text{ sec}$, can already represent a serious danger for people working in the area; at $\tau = 45 \text{ sec}$ the level is as high as a person (fig. 3). Fig. 3 shows also the maximum levels attained by the vapour in case of spillage of different volumes.

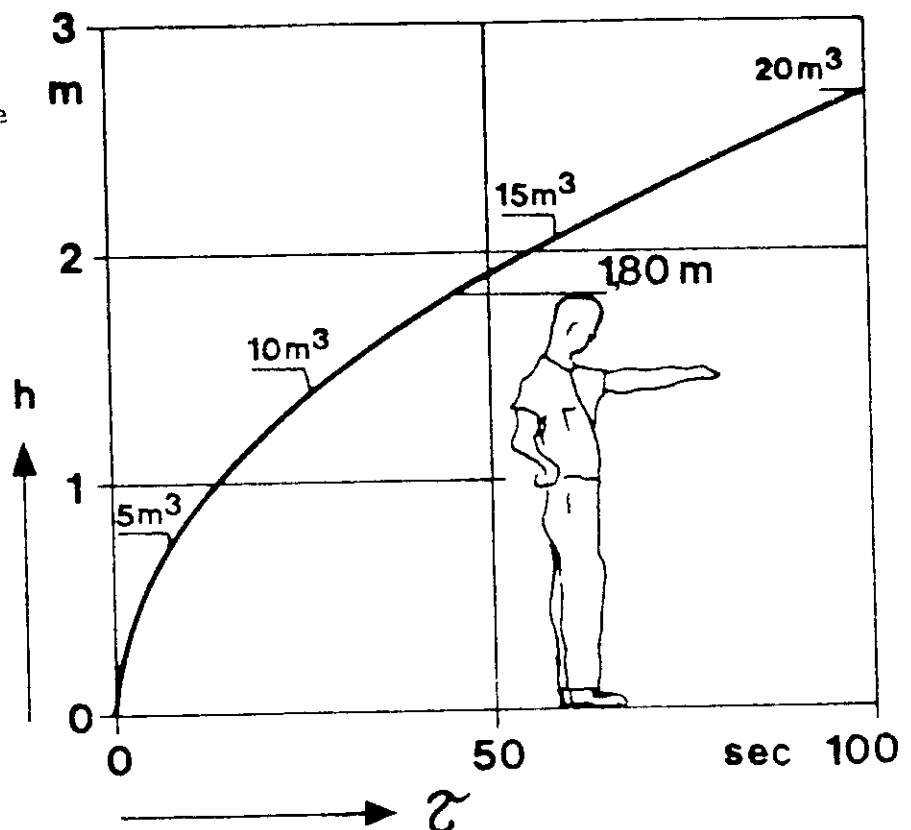


Fig. 3 : the level of the vaporised Argon in the hall as function of time and total amount of the spillage.

To foresee a ventilation system that could cope with such a situation is not realistic. The one foreseen so far could, at its best, not even handle 5% of the above quantity in such a short time. Given this, and assuming that a spillage of up to 20 m^3 of liquid Argon could occur, we should look at other possibilities to limit danger to the personnel working around the detector.

POSSIBLE MEASURES

The first thing which suggests itself is to limit the evaporation rate of the spilled Argon and make it compatible with a dedicated ventilation system, as foreseen for the detector.

This requires the following :

- thermally insulated retaining wells under the detector in the garage and operating positions,
- a pumping system to recover the liquid Argon for dumping in a suitable container,
- a gas extraction system, sucking directly from those retaining wells above the liquid level, avoiding vapours to travel in the area.

Such a system implies special fans for high density gases with a sufficient blowing power for safe ejection. On the other hand, the container mentioned above could as well serve for emergency dumping from the calorimeters in case of declaring leakage, and should then be located in the near vicinity of the apparatus.

The effectiveness of these measures determines the volume of the retaining wells, which probably need not to be bigger than 150 m^3 for a possible spillage of 20 m^3 .

It is clear that reducing the amount of liquid, or putting in volumes separating walls helps in this sense.

CONCLUSIONS

The potential dangers of operating detectors in underground halls, involving large quantities of cryogenic liquids, are serious.

However, realistic solutions to avoid consequences to the personnel in the case of a possible important spillage can be found at a reasonable cost.

ACKNOWLEDGEMENTS

Comments and contributions of Werner BIRR and René STIERLIN have been very valuable in the redaction of the present note.

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APPENDIX : CALCULATION METHOD

Exact solutions to transient heat transfer problems, i.e. characterized by final dependent heat flux and temperature field, are difficult or impossible to obtain.

To solve equation (1) we have used the approximate analytical method based on the Biot's variational principle.

This principle is applicable to one dimensional cartesian system of length L (finite or infinite), initially at the temperature t_0 , while at the time $\tau = 0$ certain boundary conditions are imposed.

It is demonstrated that the following equation, similar to the Lagrange equation in mechanics, is valid :

$$\frac{\partial V}{\partial q_i} + \frac{\partial D}{\partial \dot{q}_i} = Q_i \quad (3)$$

where :

$$V = \rho c \int_0^L t^2 dx$$

V is defined as the thermal potential

$$D = \frac{1}{2} \int_0^L \left(\frac{\partial H}{\partial \tau} \right)^2 dx + \frac{1}{2\alpha} \left(\frac{\partial H}{\partial \tau} \right)^2_{x=L} - \frac{1}{2\alpha} \left(\frac{\partial H}{\partial \tau} \right)^2_{x=0}$$

is defined as the dissipation function and α is the heat transfer coefficient ; H is a heat flow vector.

Q_i is defined as the thermal force.

V, D, Q_i, H, t are functions of n parameters $q_i, x, t,$

\dot{q}_i is intended as $\frac{\partial q_i}{\partial \tau}$ and t is the temperature above t_0 .

The equation (3) constitutes a set of differential equations, whose solution gives q_i .

To apply this method in the easiest way at our problem, we assume the following boundary conditions :

$$\begin{aligned} t_o &= 0^\circ\text{C} \\ t_\ell &= 212.5^\circ\text{C} \quad \tau = 0 \quad x = 0 \end{aligned} \quad (5)$$

The length L is taken equal to the penetration distance $\delta(\tau)$ (a q_1 parameter).

Assume :

$$H = a \left(1 - \frac{x}{\delta} \right)^3$$

where a is a constant depending by (5)

Given that :

$$-\rho c t = \frac{\theta H}{\theta x} \quad x > 0 \quad (6)$$

we have :

$$t = \frac{3a}{\rho c \delta} \left(1 - \frac{x}{\delta} \right)^2 \quad (7)$$

The constant a is :

$$a = \frac{\rho c t_e \delta}{3} \quad (8)$$

The thermal potential is :

$$v = \frac{\rho c t_e^2}{2} \int_0^\delta \left(1 - \frac{x}{\delta} \right)^4 dx = \frac{\rho \cdot c \cdot t_e^2 \cdot \delta}{10} \quad (9)$$

The dissipation function is

$$D = \frac{13}{630\alpha} (\rho c t_\ell)^2 \cdot \delta \cdot \delta^2$$

The thermal force Q_1 is :

$$Q_1 = t_\ell \left[\left(\frac{\theta H}{\theta \delta} \right)_{x=\delta} - \left(\frac{\theta H}{\theta \delta} \right)_{x=0} \right] = \frac{\rho c t_\ell}{3}$$

The penetration δ becomes :

$$\delta = 3.363 (\chi \cdot t)^{1/2}$$

The temperature distribution is given by :

$$\frac{t}{t_\ell} = (1 - x/\delta)^2$$

The quantity of heat exchanged at the time τ per unit of surface area is the following :

$$Q_{(\tau)} = \rho c \cdot t_\ell \int_0^{\delta(\tau)} \left(1 - \frac{x}{\delta(\tau)}\right)^2 dx = \frac{\rho c t_\ell \delta(\tau)}{3}$$

As Argon has the thermodynamic characteristics at boiling point at the atmospheric pressure shown in table 2, it is possible to calculate the mass vaporised per square meter of concrete and the volume of vapour produced. (1 kg of liquid Argon gives about 0.169 m³ of vapour at the boiling point)-

BOILING TEMPERATURE	°C	- 185.7
Density of vapour	Kg/m ³	5.895
Density of liquid	Kg/m ³	1390
Vaporisation heat	Kcal/kg	38.9

Table 2 : thermodynamic characteristics of Argon at atmospheric pressure (boiling point) (ref. 6).