SATURNE LINAC THREE YEARS OPERATION REPORT

by

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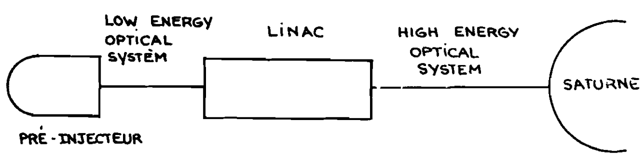
I. INTRODUCTION

In 1969 the Van de Graaff Saturne injector was replaced by a 20-MeV Linac fed by a pressurized pre-injector. (Proceedings of the 1970 International Conference on Linear Accelerators, N.A.L. Batavia, U.S.A.)

In 1970 we started to fill operation sheets for the main equipment of the synchrotron.

We shall here report on the results of a statistical study based on the modern theories of reliability and dealing with the frequency and the repartition of failures on the one hand, and with the frequency and the repartition of the duration of the said failures on the other hand.



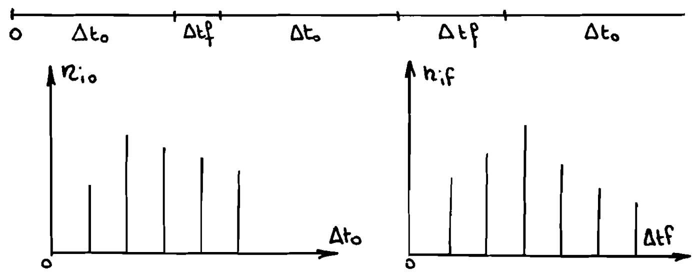
In the following we shall refer to "Preinjector" for all failures concerning the preinjector itself or the low energy optical system whatever the origin of the failure: high voltage technology, ion source, vacuum system, interlock system, and beam controls and steering.

Failures will be taken into account only when they lead to the cutting off of the beam for Physics experiments.

In the same manner, the "Linac" denomination will cover failures from both the accelerator and the high-energy optical system, with different possible origins: the rf power supply (200 MHz, 2 MW), the vacuum system, the interlock system, beam controls and steering, and rf sparking in the cavity.

II. METHOD USED TO OBTAIN OPERATION STATISTICS

Let us consider a (Δt_o) time of operation of the Linac, then a (Δt_f) time of failure (including time for repairing the failure) then a new (Δt_o) operation and so on (refer to figure below).



where,

n_{io} is the exact number of intervals of good operation, Δt_{io}, counted along the considered period of time, and

n_{if} is the exact number of failures with a duration, Δt_{if}, counted along the same period of time.

One may write:

$\Sigma\, n_{if} \cdot \Delta t_{if} = T_f$ total duration of the failures

$\Sigma\, n_{if} \cdot \Delta t_{if} + \Sigma\, n_{io} \cdot \Delta t_{io} = T_m$ total machine time.

However, $\Sigma\, n_{if} \cdot \Delta t_{if}$ is of the order of 100 hours and negligible with respect to $\Sigma\, n_{io} \cdot \Delta t_{io} >$ 3000 hours.

Therefore, $\Sigma\, n_{io} \cdot \Delta t_{io} \# T_m$.

Besides, $\Sigma\, n_{io} = \Sigma\, n_{if} = N$.

The probability to have an interval of operation greater than a given Δt_{ko} is:

$$R = 1 - \frac{\Sigma_o^k n_{if}}{N} = \text{Probability } \{\Delta t_o > \Delta t_{ko}\} ,$$

which is the reliability of the system expressed in percentage.

In the same manner, one can define for the failures:

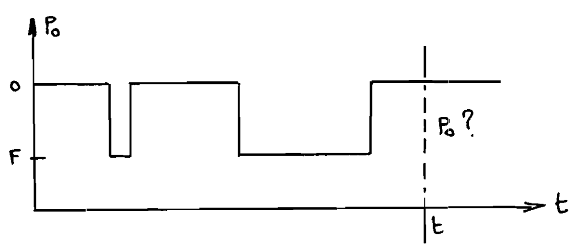
$$M = 1 - \frac{\Sigma_o^k n_{if}}{N} = \text{Probability } \{\Delta t_f > \Delta t_{kf}\} .$$

The two functions of repartition may be plotted as follows: (see a and b in next column).

In semi-log plotting we generally get straight lines or series of straight lines, which means that the repartition functions are exponentials or series of exponentials.

It is then possible to compute the values of the constants that characterize the different types of operation or the durations of the failures (λ_1, λ_2, or μ_1, μ_2). (See c and d in next column.)

The availability of the system is calculated from the slopes of these two curves. In fact these data do not describe any more the probability to get a failure after a Δt_o interval, or a failure duration greater than Δt_f; but, considering these two probabilities, it expresses the probability to be in either condition at a given time counted from the zero time when the system is started.



The probability to be still in operation at time t is:

$$P_o = \frac{\mu}{\mu + \lambda} + \frac{\lambda}{\mu + \lambda} e^{-(\lambda + \mu)t}$$

This includes the possibility to have had previous failures that have been repaired. The probability to be in the condition of failure at time t is:

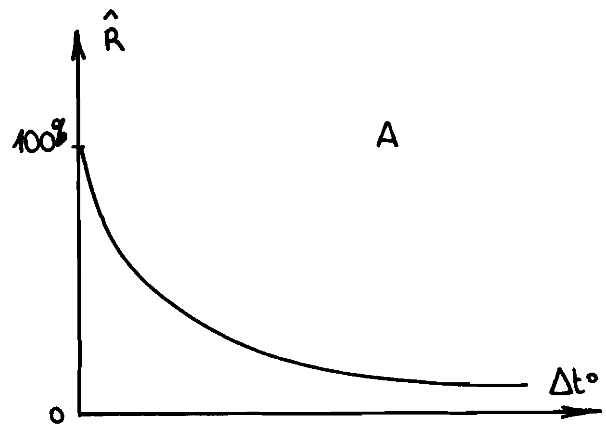
$$P_f = 1 - P_o$$

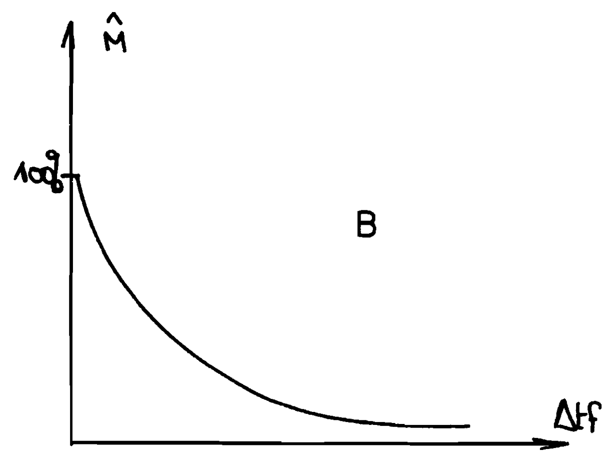
$$P_f = \frac{\lambda}{\lambda + \mu} (1 - e^{-(\lambda + \mu)t}) ,$$

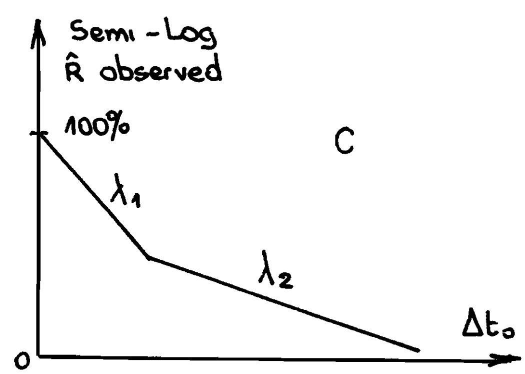
where

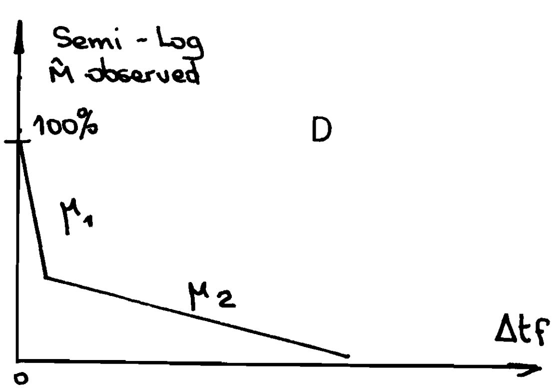
P_o is the availability of the system at time t, and

P_f is the unavailability of the system at time t.









III. RESULTS WITH THE SATURNE INJECTOR

The results obtained from the operation sheets are described by the following figures:

1 - 1970 Linac operation scattergramm
2 - 1971 Linac operation scattergramm
3 - 1972 Linac operation scattergramm
4 - Reliability of the Linac (1970, 1971, 1972)
5 - 1970 Linac failure scattergramm
6 - 1971 Linac failure scattergramm
7 - 1972 Linac failure scattergramm
8 - Maintainability of the Linac (1970, 1971, 1972)
9 - 1970 Pre-injector operation scattergramm
10 - 1971 Pre-injector operation scattergramm
11 - 1972 Pre-injector operation scattergramm
12 - Reliability of the pre-injector (1970, 1971, 1972)
13 - 1970 Pre-injector failure scattergramm
14 - 1971 Pre-injector failure scattergramm
15 - 1972 Pre-injector failure scattergramm
16 - Maintainability of the pre-injector (1970, 1971, 1972)

From these curves we can, by use of the preceding formulas, find out the values of the essential data. They can be found in Table I.

The mean times of stabilization ($1/\lambda_{average}$) are:

linac		pre-injector	
1970	20 hours	1970	2,3 days
1971	12 hours	1971	3,3 days
1972		1972	2,6 days

IV. GENERAL REMARKS

The examination of the curves brings out the following remarks:

A. Linac

1. Operation (Figure 4)

a. 80% of the operation durations are shorter than 12 hours. If, from 1970 to 1971, the situation could be considered as stationary, an effect of fatigue of the equipment can be noticed in 1972.

One must also remember that in 1972 the time allowed to the maintenance of the equipment has been reduced due to the necessity to install new equipment (deuteron injection with ramping of the energy).

b. The probability to operate for more than one day is 10%.

c. The probability to operate for more than 5 days is about 1%.

2. Duration of failures (Figure 8)

a. 80% of the failure durations are shorter than 15 minutes. From this point of view the situation is fairly stable since 1970, and one may say that the typical mode of operation is: 10 hours of operation; 15 minutes of failure.

These failures are generally due to the rf equipment (crow-bars) or to sparking in the cavity when deuterons are accelerated, which requires a higher field in the first gaps of the Linac to compensate for the poor transit time factor.

TABLE I

	Linac			Pre-injector		
	1970	1971	1972	1970	1971	1972
$1/\lambda$	21 h	21 h	12 h	2,3 d	3,3 d	2,6 d
$1/\mu$	23'	25'	18'	1 h	1 h	1 h
T_o	3800 h	5000 h	3250 h	3800 h	5000 h	3250 h
T_f	57 h	115 h	83 h	258 h	166 h	190 h
N_f	184	249	241	77	71	82
P_o $t = \infty$	98 %	98 %	97,5 %	98,2 %	98,7 %	98,4 %
P_f $t = \infty$	2 %	2 %	2,5 %	1,8 %	1,25%	1,5 %

b. The probability to get a failure duration longer than 30 minutes is 10%.

c. The probability to get a failure duration longer than 4 hours is 1%.

One can also remark that the availability is P_o = 98%. In spite of a rather short typical operation duration, and on the account of fast repairing, the Linac is, on the average, of good availability.

B. Preinjector

1. Operation (Figure 12)

a. The probability to operate for less than one day without failure is 40%.

b. The probability to operate for more than 7 days is 10%.

c. The probability to operate as follows is 1%: 1970, for more than 15 days; 1971, for more than 23 days; and 1972, for more than 30 days.

Clearly, improvements have been obtained from one year to another.

2. Duration of failures (Figure 16)

a. The probability to have a failure duration shorter than 15 minutes is 75%.

b. The 10% probability of failure applies as follows: 1970, duration > 3 hours; 1971, duration > 2 hours; and 1972, duration > 4.5 hours.

c. Failures of long duration have been more important in 1970 and 1972 than in 1971.

The typical mode of operation is more difficult to release, it is something like: one day of operation; 30 minutes of failure.

The availability is still high, a precise computation gives a 98% value.

Most failures are of short duration, they are mainly due to filling of liquid nitrogen traps and interlocking systems.

Failures with long durations are due to changes of cathodes and of the focusing tube. The technique of pressurized vessel evidently leads to longer repairing times, which are, however, compensated by the advantages of much higher dielectric strengths. We could also discover an erosion of the environment during repairing activities which often leads to the necessity of a new intervention a few days later. The installation of new equipment or modification of existing equipment also leads to similar results, that is, the erosion of the general system capability (defects in contacts, elements of the interlock system running out of service..).

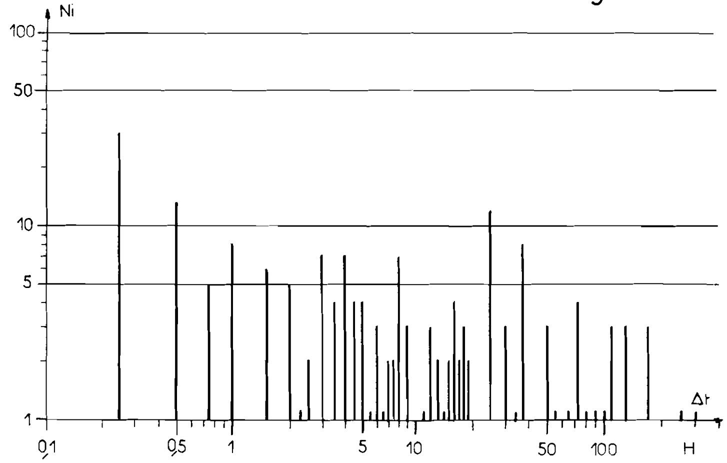
V. CONCLUSIONS

This study enabled to replace subjective appreciations of the condition of the accelerator by precise data, which will facilitate our politics of maintenance and modifications.

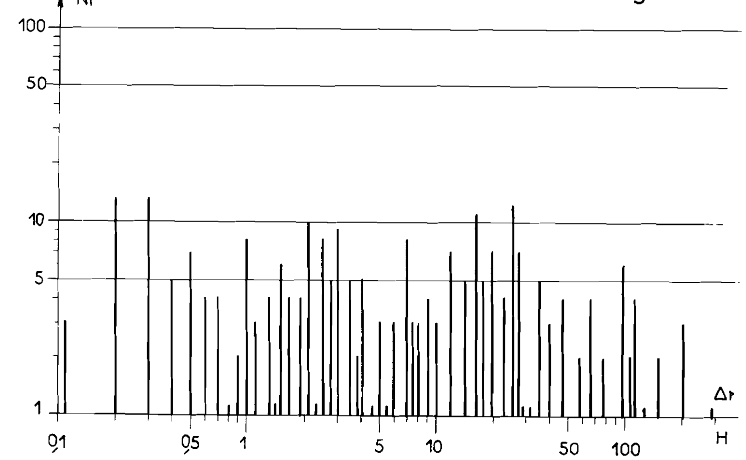
For example, it seems necessary to reduce the mean duration of the preinjector failures and to increase the mean time of operation of the Linac, which implies two different types of action.

The study of the modes of failure, the computation of the optimized periods of maintenance and the management of the spares should bring the cost of one hour of beam to a minimum, taking into account the desired type of operation.

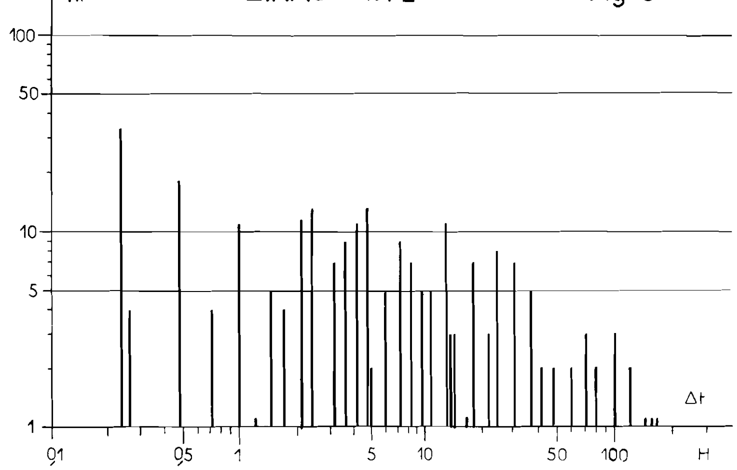
LINAC 1970 Fig 1



LINAC 1971 Fig 2



LINAC 1972 Fig 3



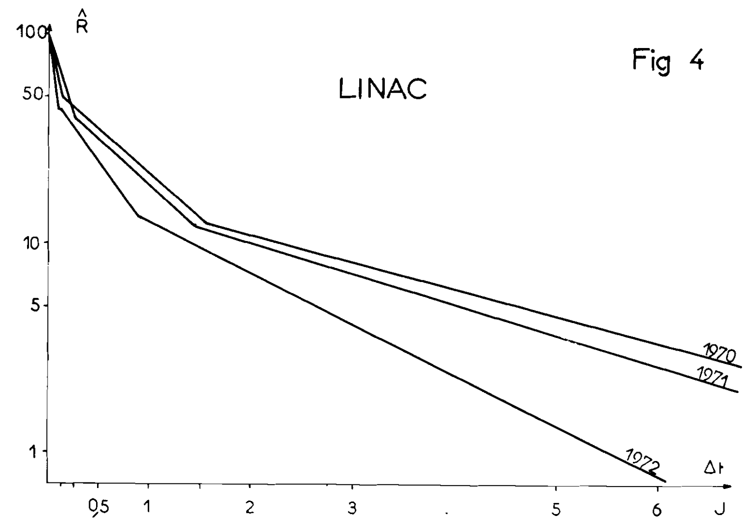
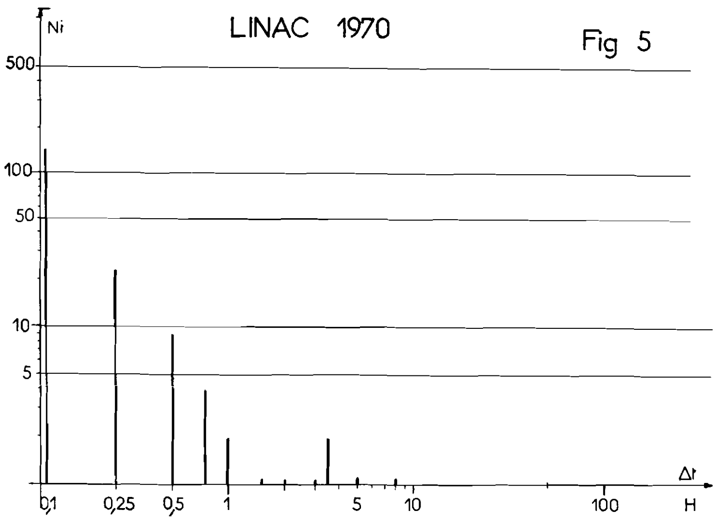
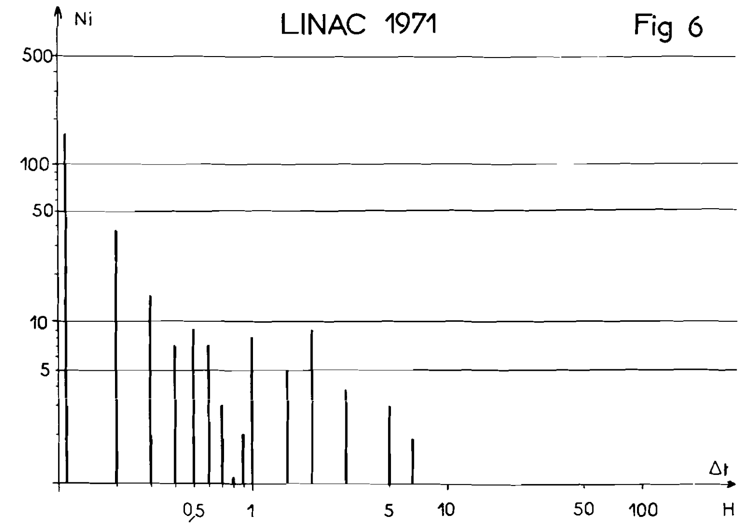


Fig 4



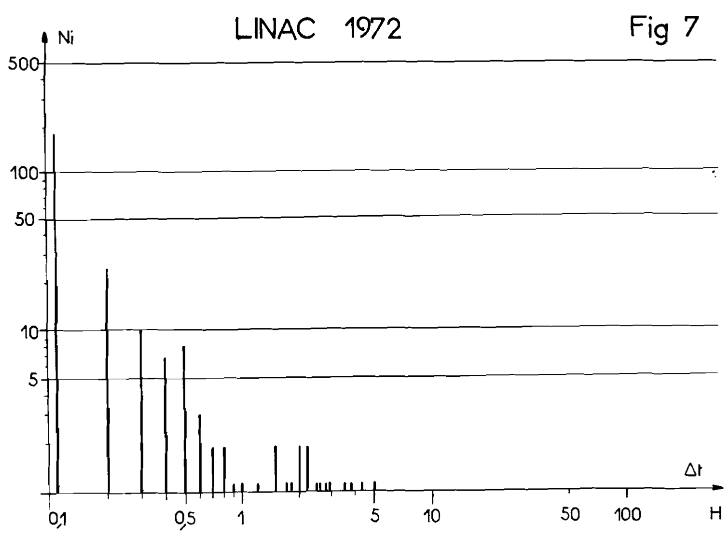
LINAC 1970

Fig 5



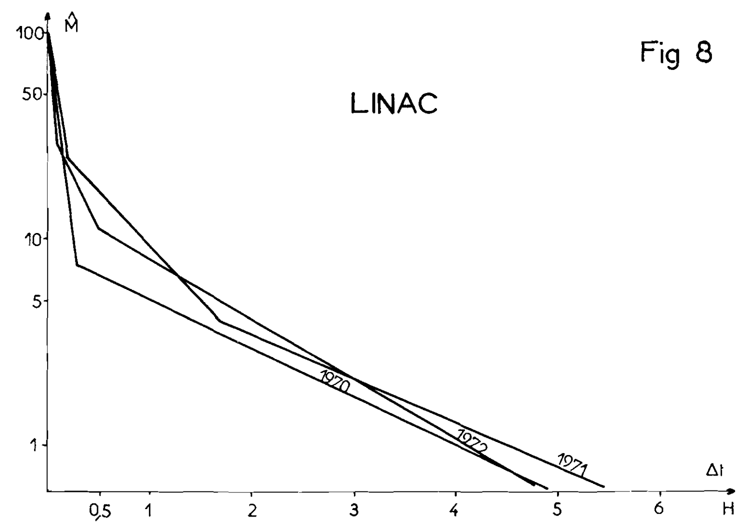
LINAC 1971

Fig 6



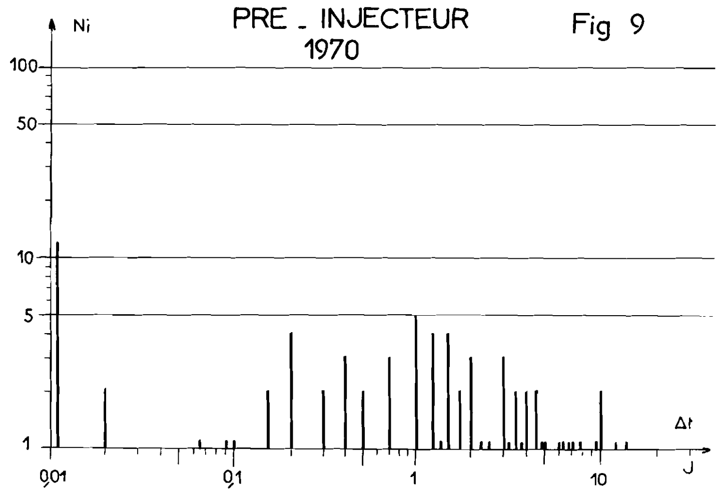
LINAC 1972

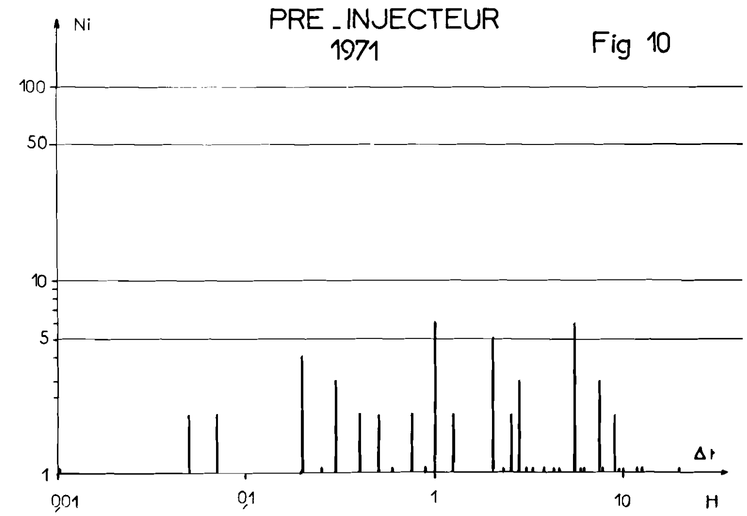
Fig 7

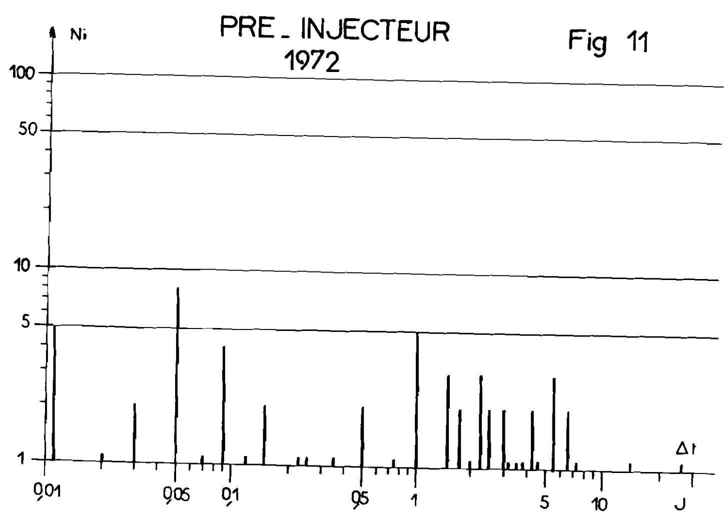


LINAC

Fig 8


PRE - INJECTEUR
1970
Fig 9
Ni
100
50
10
5
1
Δt
0,01
0,1
1
10
J


PRE - INJECTEUR
1971
Fig 10
Ni
100
50
10
5
1
Δt
0,01
0,1
1
10
H


PRE - INJECTEUR
1972
Fig 11
Ni
100
50
10
5
1
Δt
0,01
0,05
0,1
0,5
1
5
10
J

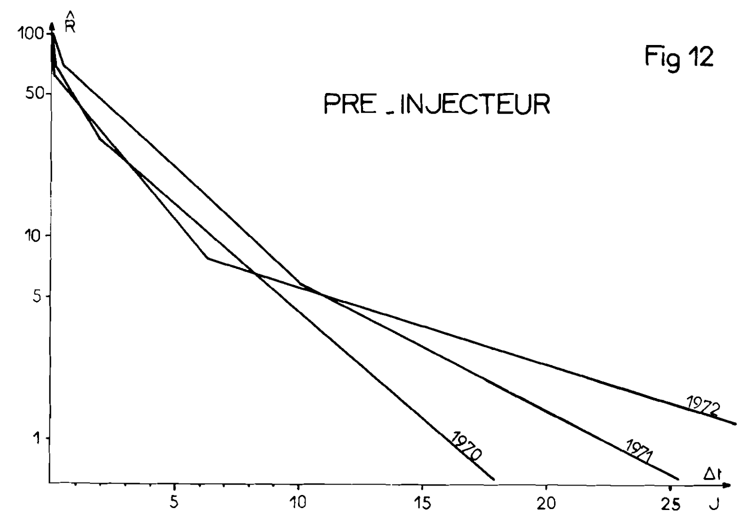


Fig 12
PRE - INJECTEUR
$\hat{R}$
100
50
10
5
1
1970
1971
1972
Δt
5
10
15
20
25
J

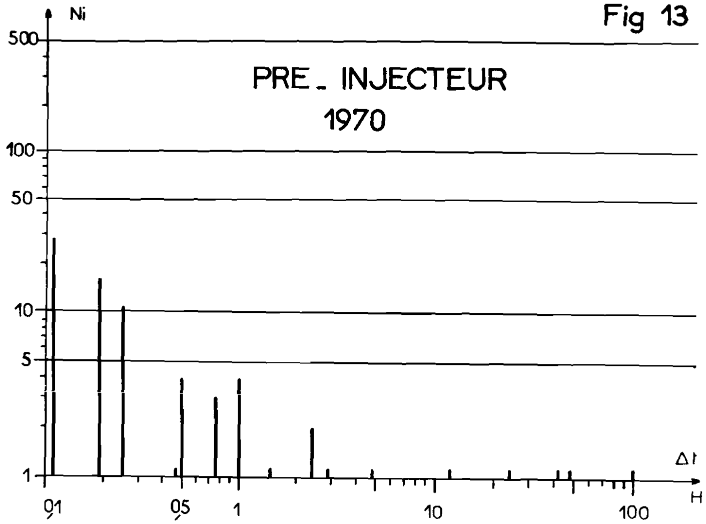


Fig 13

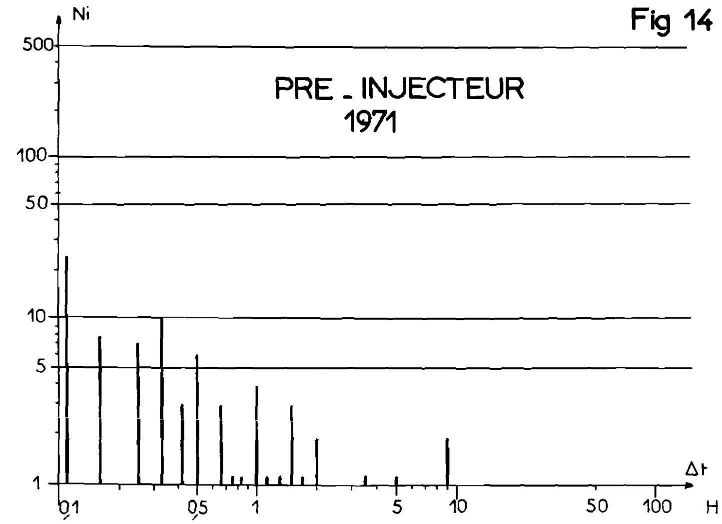


Fig 14

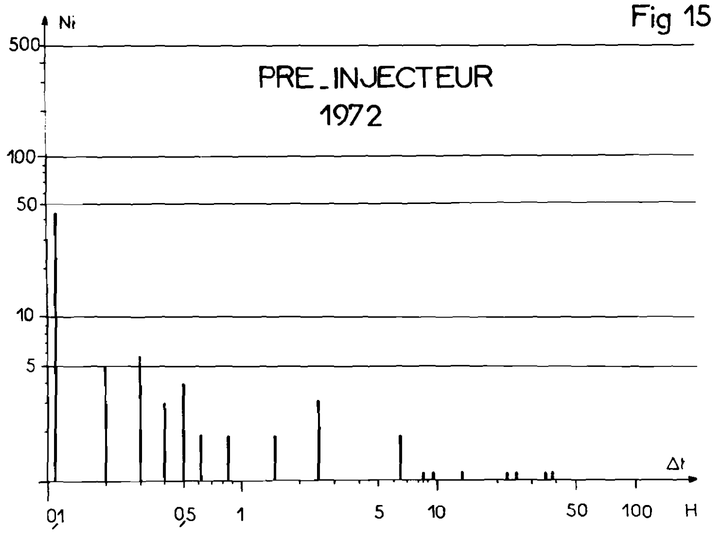


Fig 15

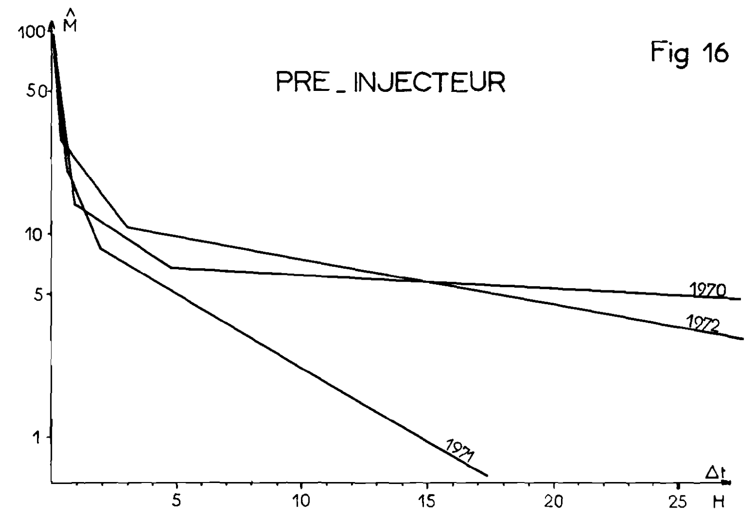


Fig 16