SRSC-223
9/94

SILENE

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Table 8. Characteristics of the First Pulse of the Experiments in the 300-mm-diam Cylinder.

Experiment Number	Time to Peak of Pulse[a] (sec)	Solution: Height at Peak Power (cm)	Solution: Volume at Peak Power (liter)	Rate of Reactivity Addition (dollars/sec)	Minimum Doubling Time (sec)	Inverse Period (sec^{-1})	Specific Energy in Pulse (10^{12} fissions/cm^3)
CRAC 01	232	329	226	0.00341	2.9	0.24	1.2
CRAC 02	72	255	173	--	0.18	3.9	1.0
CRAC 03	427	274	186	0.00141	5.0	0.138	0.93
CRAC 04	197	331	225	0.00391	3.2	0.216	1.0
CRAC 05	21.6	82.2	56.0	0.0667	0.060	11.6	1.1
CRAC 06	22.8	82.4	56.2	0.0740	0.050	13.9	1.2
CRAC 07	3.9	29.7	20.5	0.786	0.00157	442	2.0
CRAC 08	3.1	29.3	20.3	0.746	0.00069	1004	4.0
CRAC 09	6.4	47.1	32.3	0.247	0.015	46	1.4
CRAC 10	6.6	44.0	30.2	0.0772	0.0176	39.4	1.4
CRAC 11	--	--	--	--	--	--	--
CRAC 12	65	46.3	31.8	0.0156	0.275	2.52	1.2
CRAC 13	7.5	53.3	36.5	0.157	0.012	57.7	1.4
CRAC 14	12.0	45.4	31.1	0.0992	0.049	14.1	1.3
CRAC 15	4.0	43.6	29.9	0.253	0.033	20.8	1.2
CRAC 16	11.2	44.1	30.3	0.0755	0.242	2.86	1.2
CRAC 17	11.7	44.3	30.4	0.0820	0.177	3.92	1.2
CRAC 18	43.8	43.8	30.1	0.0168	0.52	1.33	1.2
CRAC 19	16.2	44.9	30.8	0.0870	0.036	19.2	1.1
CRAC 20.1	2.2	28.4	19.7	0.674	0.0061	114	1.0
CRAC 20.2	2.2	28.4	19.7	0.684	0.0063	110	1.1
CRAC 20.3	2.4	28.6	19.8	0.691	0.0066	105	1.0
CRAC 20.4	3.4	29.2	20.2	0.685	0.00118	587	2.9
CRAC 20.5	2.5	28.5	19.7	0.616	0.0058	120	1.1
CRAC 21	17.0	45.4	31.1	0.0833	0.032	21.6	1.0
CRAC 22	4.6	28.9	20.0	0.501	0.00147	471	2.1
CRAC 23	4.6	39.6	27.2	0.310	0.0058	120	1.6
CRAC 24	--	--	--	--	--	--	--
CRAC 25	7.1	33.0	22.2	0.871	0.00153	453	1.7
CRAC 26	8.3	33.6	23.1	0.638	0.0027	252	1.7
CRAC 27	4.7	41.3	28.4	0.315	0.012	58	1.2
CRAC 28	8.8	42.3	29.1	0.226	0.011	63	1.3
CRAC 29	12.3	44.9	30.8	0.0808	0.032	21.7	1.1

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Report SRSC n° 223- September 1994

SILENE Reactor

Results of selected typical experiment

Francis BARBRY

CEA INSTITUT DE PROTECTION ET DE SURETE NUCLEAIRE
DEPARTEMENT DE RECHERCHES EN SECURITE
SERVICE DE RECHERCHES EN SURETE ET CRITICITE
Centre d'Etudes de VALDUC - SRSC - 21120 Is-sur-Tille - France - ☎ 80 23 40 00

SILENE

SUMMARY OF REFERENCE DATA AND LIST OF THE MOST REPRESENTATIVE EXPERIMENTS

SUMMARY

This document recapitulates the most representative experimental results found on the Silene reactor in a configuration without shielding in studies on solution criticality accidents. Most of this data is relative to the nominal operating concentration of the reactor, i.e. 71 g/l, but in the appendix we have also included the results of a test series at 220 g/l as well as the results of the reactor calibration campaign.

This set of reference data can of course be used by the operator, but was initially compiled for validating computing models of accidental criticality excursions.

Two documents reviewing the lessons learned from the SILENE experiments are given in appendix.

Il y a eu quelques erreurs de pages entre le français et l'anglais lors d'un 1er tirage du rapport. Pour éviter un gaspillage ces exemplaires ont été conservés pour la diffusion interne SRSC, les documents partis à l'extérieur ayant été rectifiés. Les pages inversées concernent les tableaux, symboles, ... (pages entre le texte principal et les figures illustrant les expériences SILENE)

CONTENTS

SILENE

1 - GENERAL INFORMATION AND SILENE OPERATING PRINCIPLE

Silene is a homogeneous experimental reactor using a fissile solution of uranyl nitrate (U enriched in ^{235}U at 92.7%) as fuel.

The core is in the form of a small annular tank located in the middle of a large concrete room referred to as a "cell". The fissile solution required for operation of the reactor is prepared in a laboratory located in the cell basement (ref. 1 to 3).

The general operating principle of the reactor is as follows:

- The fissile solution, previously adjusted to the Silene operation concentration in a special large capacity tank, is pumped into the core up to predetermined supercritical level. During this phase, a control rod is present in the core to avoid divergence.

- The "divergence" power excursion is then produced by removing the rod from the core using a procedure which depends on the operating mode selected for the planned experiment.

- When the experiment has been completed, the fissile solution containing the radioactive fission products is dumped into a special tank located in a shielded room, allowing rapid access into the cell.

A ventilation circuit blows continuously through the upper part of the core to dilute radiolysis gases formed. After the time necessary for their radioactive decay, these gases are removed through ad hoc filtration systems.

2 - THE REACTOR CORE AND ITS VARIOUS MODES OF OPERATION

2.1 - Description of the core

The Silene core is in the form of a 1 m high, 360 mm diameter stainless steel core with a 70 mm diameter internal channel (Figure 3

- **Main dimensions**

External cylinder 360/368 mm
Internal channel 70/76 mm
Tank bottom thickness 36 mm
Cover thickness 30 mm

- **Composition of the stainless steel used (grade ZZ-CN 18.10)**

Isotope	Number of atoms x 10^{-24} cm^{-3}
Carbon	1.200 10^{-4}
Silicon	1.709 10^{-3}
Chromium	1.661 10^{-2}
Iron	5.922 10^{-2}
Nickel	8.178 10^{-3}

2.2 - The cell

The core is located in a concrete room with dimensions of 19 x 12 x 10 m and walls 1.5 m thick (Figure 4).

The concrete composition is as follows:

Isotope	Number of atoms x 10^{-24} cm^{-3}
Hydrogen	1.035 10^{-2}
Boron-10	1.602 10^{-6}
Oxygen	4.347 10^{-2}
Aluminum	1.563 10^{-3}
Silicon	1.417 10^{-2}
Calcium	6.424 10^{-3}
Iron	7.621 10^{-4}

2.3 - The fissile solution at nominal operating concentration

The fissile solution used is uranyl nitrate, which, at the nominal concentration of 71 $g.l^{-1}$ chosen for reactor operation, has the following mean properties:

Density	1.161 $g.cm^{-3}$
Total U concentration	71 $g.l^{-1}$
Acidity H+	2 N
^{235}U enrichment	92.7%

giving the following composition :

Isotope	Number of atoms x 10^{-24} cm^{-3}
Hydrogen	6.258 10^{-2}
Nitrogen	1.569 10^{-3}
Oxygen	3.576 10^{-2}
Uranium-234	1.060 10^{-6}
Uranium-235	1.686 10^{-4}
Uranium-236	4.350 10^{-7}
Uranium-238	1.170 10^{-5}

This is a mean composition used as reference in the calculations, since it is obvious that the value of these parameters must have varied during the experiments, reprocessing and various adjustments.

The reactor calibration experiments (Ref.3) were carried out at various concentrations. A series of specific experiments was performed at a concentration of about 200 $g.l^{-1}$. However, the mean nominal concentration during reactor operation is 71 $g.l^{-1}$.

2.4 - Control rods and the corresponding control devices

Divergence in accordance with the selected procedure is initiated by rapidly or slowly displacing a rod at a predetermined speed within the central core channel. The rods are annular, allowing for the possibility of adding test capsules in the central channel which then act as an irradiation channel.

There are several types of rods, wrongly called control rods, but which are actually reactivity insertion rods. The two most commonly used are made of cadmium and boron carbide. A special rod was designed for "boiling" type experiments which require reactivities of up to 5800 pcm (7.3 $).

The reactivity values of these rods for the 71 $g.l^{-1}$ concentration are as follows:

Cadmium rod	$\Delta kp < 3220$ pcm (4.1 $)
B_4C rod	$\Delta kp < 4560$ pcm (5.8 $)
Special "boiling" rod	$\Delta kp < 5800$ pcm (7.3 $)

Only the "Cadmium" rod was calibrated with precision (Ref. 4) since it was the only rod authorized for high reactivity insertions ("free evolution" mode).

Figures 5 show the rate of reactivity insertion with the C rod and the "critical" position of the rod respectively, for different heights of the fissile solution within the core.

There are two types of control mechanisms for removing the rod from the core:

. a mechanical device allowing rod displacements ≤ 20 $cm.s^{-1}$;

. a pneumatic device which can eject the rod at about 1.5 $m.s^{-1}$.

It should be understood that when constructed, Silene had a single mechanical device operating as follows :

- in "pulse" ejection of the rod at 20 $cm.s^{-1}$
- in "free evolution" rod output at 2 $cm.s^{-1}$
- in "steady state" rod displacements at 2 $mm.s^{-1}$

Due to the fact that a significant percentage of "pulses" resulted in premature initiation of the chain reaction and therefore did not allow pure reactivity "steps", it was decided two years later that a pneumatic device would be added to allow faster rod ejections to avoid any initiation of divergence before the rod was totally removed from the core. Since this period, no "pulses" have "failed".

2.5 - Operating modes

Depending on the reactivity present within the core, the rod ejection speed, and the presence or absence of an auxiliary neutron source, Silene can operate in one of three different modes called "PULSE", "FREE EVOLUTION" and "STEADY STATE".

- Operation in "Pulse" mode is obtained by ejection of the rod at high speed (0.2 or approx. 2 $m.s^{-1}$) with or without the presence of an auxiliary neutron source, allowing it to obtain a very high power peak in a short time (up to 1000 megawatts in a few milliseconds). This is therefore a fast transient. The reactivity in this mode of operation is limited to 2400 pcm due to a pressure wave generated in the liquid (value limited to 8 bars absolute pressure in the Silene configuration).

- "Free evolution" operation takes place by removal of the rod at low speed (< 2 $cm.s^{-1}$) in the presence of an auxiliary neutron source[1]. The reactivity engaged under normal operation cannot exceed 4000 pcm, but under exceptional circumstances can be increased to 5800 pcm if it is required to bring the fissile solution to boiling state.

- "Steady state" operation is obtained by having the rod controlled by a control sequence. Rod displacements take place very slowly (about

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[1] Reminder of the role of the external neutron source:
When the presence of an external neutron source is indicated in the specifications of the experiment, this refers to a 100 mCi Am-Be source located at the bottom of the core tank (Figure 3). Its role is to generate a deterministic initiation of the chain reaction by increasing the initial neutron population in the system (Ref. 5). It is obvious that to obtain a high reactivity "step", it is better to operate without an external neutron source and with the highest possible rod ejection speed so that all reactivity is inserted before the first persistent neutron chain is initiated.

2 mm.s^{-1}) in the presence of an auxiliary neutron source. In this mode of operation, Silene is brought to a predetermined stable power level.

The performances of Silene in the three operating modes described above are illustrated and specified in Figure No. 6.

3 - REACTOR DIAGNOSTICS

3.1 - Total number of fissions

The main objective of an experimental reactor is to have the closest possible control over the total released energy; in our case, this means determining the total number of fissions during the experiment.

Two methods can be used for this purpose, namely gamma spectrometry on the fission products formed, and thermal balance.

- **Spectrometry**

The total number of fissions carried out during an experiment can be determined by taking a sample of the fissile solution after the experiment and analyzing judiciously selected fission products by gamma spectrometry. In the case of Silene, the fission products used are generally as follows:

Radionuclide	Energy KeV	Period	% emission	Fission yield
^{99}TC	140.52	66.02 h	89.4 %	6.16 %
^{132}Te	228	78.8 h	90 %	4.26 %
^{143}Ce	293.1	33 h	46 %	5.91 %
^{103}Ru	497.1	39.35 dy	89.7 %	3 %
^{95}Zr	756.7	65.2 dy	54 %	6.2 %
^{99}Mo	739.4	66.02 h	11.82 %	6.16 %

Applied strictly, this method provides an accuracy of 5%, taking into account all statistical errors as well as errors due to the data libraries used.

- **Thermal balance**

It was observed on Silene that during short duration experiments (<2 minutes), the system was significantly adiabatic due to extremely low thermal exchange coefficients with the environment. Heating the fissile solution can therefore be used as a method of diagnosis provided that the temperature of the solution is uniform, in other words if there is enough mixing by radiolysis gases, and also provided that the thermal characteristics of the solution are well known.

In the case of uranyl nitrate solutions, we can establish the thermal balance by using the following relationship determined from experiments carried out in the Valduc laboratory:

$$Cp = 0.0008154 \times C_{U_t} - 0.06\ H +$$

At a concentration of 71 $g.l^{-1}$, C_p is approximately 0.82 $Cal.g^{-1}\ °C^{-1}$.

3.2 - Monitoring power and radiation emission rate

In order to monitor the evolution of reactor power, different types of detectors were used (fission chambers, scintillators, ionization chambers) which were power-calibrated based on a comparison between their signal and the number of fissions resulting from the previous diagnosis.

Certain precautions must be taken, however, to avoid errors due to:

- the time-of-flight of neutrons if measuring in thermal neutrons,

- radiation diffused by the concrete walls which, in particular, could significantly distort monitoring of the sudden power drop after the first peak.

On Silene, special collimated detectors placed behind shields were designed to overcome these difficulties.

Dose-calibrated detectors were used for measuring neutron and gamma radiation dose rates (kerma rads for the neutron radiation and tissue rads for the gamma radiation).

3.3 - Routine diagnosis

Since gamma spectrometry is long and complicated, routine diagnosis of the reactor is performed using:

1. Activation detectors (S, Au, Cu, Mg) calibrated during calibration experiments,

2. Detectors to monitor the power of the reactor, whose information is sent to a data acquisition and processing system.

3.4 - Temperature and pressure measurements

Aside from the nuclear detectors mentioned above, the only nuclear instruments installed permanently on the reactor are two thermocouples (chromel-alumel) placed in the fissile solution at 20 and 30 cm from the bottom of the tank, and a pressure sensor (CEC BELL tight-wire type sensor) placed on the bottom of the core tank in the sole aim of ensuring that the pressure wave generated at the first power peak does not exceed 8 bars, the maximum limit allowed under the safety conditions of this facility.

Specific pressure measurements were also taken inside the fissile solution (Ref. 6).

3.5 - Measuring the fissile solution level

Two independent devices are used to measure the height of the fissile solution pumped into the core tank.

The first device is based on an "electromagnetic" principle and consists of making an electrical contact on the surface of the liquid. The corresponding assembly is thus installed on the upper part of the core.

There is another device at the bottom of the core tank that measures the level ultrasonically, consisting of two detectors immersed in the solution. The first detector sends a signal to the surface of the liquid and processes the information through the second detector referred to as the "reference" detector. The reference detector sends a signal to a fixed reference surface, making it possible to account for variations in wave velocity as a function of the density and temperature of the fissile solution.

4 - NEUTRON DATA FOR REACTIVITY CALCULATION WITH 71 $g.l^{-1}$ CONCENTRATION

4.1 - Neutron data

In order to obtain the reactivity values that appear in the result tables, we used the following neutron data determined by CEA computing codes (Apollo, Moret).

. Lifetime of prompt neutrons at 71 g/l $\bar{\ell} = 36\ \mu s$

. Delayed neutrons

GROUP	1	2	3	4	5	6
εi	1.28	1.24	1.26	1.23	1.26	1.20
βi	0.021	0.139	0.126	0.252	0.074	0.026
λi s	0.0124	0.0305	0.111	0.301	1.13	3.0

εi represents the efficiency of each group of delayed neutrons.

$$\beta_{eff} = \sum_{i=1}^{6} \varepsilon_i \times \beta_i = 794 \text{ pcm}$$

4.2 - Reactivity calculations

In the result tables, a distinction is made between two reactivity values Δk.

Δk_1 is defined as the reactivity present at the time of the first peak, corresponding to application of the Nordheim formula starting from the minimum period measured in the rise of the first peak.

$$\rho(\text{pcm}) = \frac{\bar{\ell}/T_e}{1 + \bar{\ell}/T_e} \quad \frac{1}{1 + \bar{\ell}/T_e} \quad \sum_{i=1}^{i=6} \quad \frac{\epsilon_i \ \beta_i}{1 + \lambda_i \ T_e}$$

Δk_p is defined as the total potential reactivity to be introduced in the core. In the case of a reactivity "step", implying an experiment where total reactivity is reached even before the first peak occurs, then $\Delta k_p = \Delta k_1$.

In the case of a reactivity ramp occurring in the presence of an external neutron source (this is often the case in "free evolution" experiments), then total reactivity is not reached in the core at the time the first peak occurs, and $\Delta k_p \neq \Delta k_1$.

For pure reactivity steps, an experimental relationship was established between Δk^P and ΔH (height of the additional solution above the delayed critical height).

For high reactivity levels (in "boiling" type experiments), which are not allowed in the "Pulse" mode in order to avoid steps that are too abrupt, the reactivity could only be calculated. Figure 8 illustrates the calculated evolution of k_{eff} as a function of the height of the solution. The "fit" below represents this variation of k_{eff} on the Silene reactor.

$$Keff = 0.68276 + 1.194 \ 10^{-2} \times H - 9.905 \ 10^{-5} \times H^2$$

5 - RESULTS OBTAINED WITH THE 71 $g.l^{-1}$ CONCENTRATION

- Presentation of results

The most representative results of the Silene experiments are given in the form of:

- tables summarizing the main characteristics, the meaning of the symbols used being given beforehand,

- graphs illustrating the evolution in time, in experiments on the following parameters:
  . power, energy
  . temperature of the fissile solution
  . pressure at the first power peak
  . neutron and gamma dose rate (in general at 4 m from the source center).

To simplify presentation, however, the experiments have been classified into different catagories:

1 - experiments with slow kinetics: referring to all experiments carried out with a reactivity insertion of less than β (β being the prompt critical state ≈ 794 pcm) $pcm = 10^{-5}$ ∴ $k_{PC} = 1,00794$

2 - experiments at the prompt critical state ($\rho \neq \beta$)

3 and 4 - experiments with fast kinetics corresponding to reactivity steps ($\rho >> \beta$ and $\Delta k_p = \Delta k_1$) with and without external neutron source.

5 - experiments corresponding to reactivity ramps: referring to all experiments carried out in the "free evolution" mode.

6 - "boiling" experiments. These are the experiments carried out in the "free evolution" mode but using a special reactivity rod allowing the insertion of more than 7 $ of reactivity, thus bringing the reactor fissile solution to a boiling state.

7. Enfin nous avons isolé une dernière catégorie d'expériences pour leur intérêt sur le plan de la qualification des modèles de calcul : il s'agit d'une série d'expériences réalisées à une réactivité constante (Δk_p = 2350 pcm) mais avec des vitesses d'introduction de réactivité différentes obtenues en jouant sur la vitesse d'éjection de la barre cadmium.

Il est à noter qu'un dossier complet sur chaque expérience est archivé à Valduc et qu'il est possible d'y trouver des informations plus détaillées telles que le listing de l'évolution du nombre total de fissions en fonction du temps ou la position précise de la barre au moment du 1er pic de puissance.

Une synthèse des résultats de SILENE est donnée dans les références 7 et 8.

Références

Réf. 1 Brochure SILENE : document CEA/IPSN

Ref.2 F.BARBRY, "Fuel solution Criticality Accident studies with the SILENE reactor : Phenomenology, consequences and simulated intervention" International Seminar on Criticality studies programs and needs. DIJON (France) SEPT - 1983

Ref. 3 F. BARBRY, "Compte rendu des essais d'étalonnage du réacteur SILENE"
Rapport CEA/SEESNC n° 124, 1975

Ref. 4 F. BARBRY, Etalonnage de la barre cadmium du réacteur SILENE
Note technique SRSC n° 92.11, Sept. 1992

Ref. 5 G. HANSEN, "Assembly of fissionable material in the presence of a weak neutron source", NSE 8-709-719, 1960

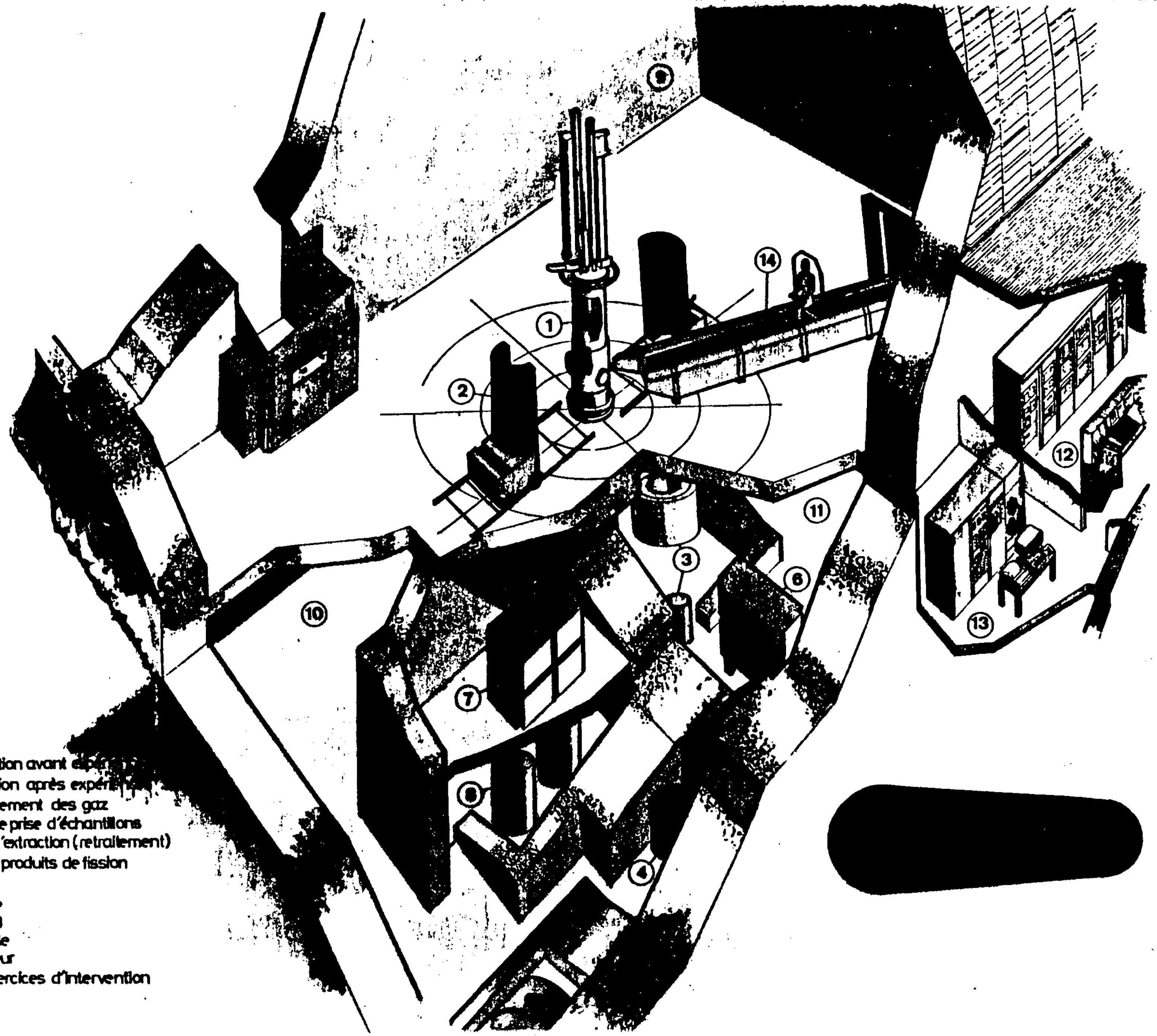
Ref. 6 F. BARBRY, J.P. ROZAIN, "Formation of radiolysis gas and the appearance of a pressure increase during a criticality excursion in a fissile solution" Trans. Am. Nucl. Soc., 59, 181, (1989)

Ref. 7 F. BARBRY, "A review of the SILENE criticality excursion experiments". Topical meeting on Physics and Methods in Criticality Safety, 34, 40, Sept 993, NASHVILLE, TN

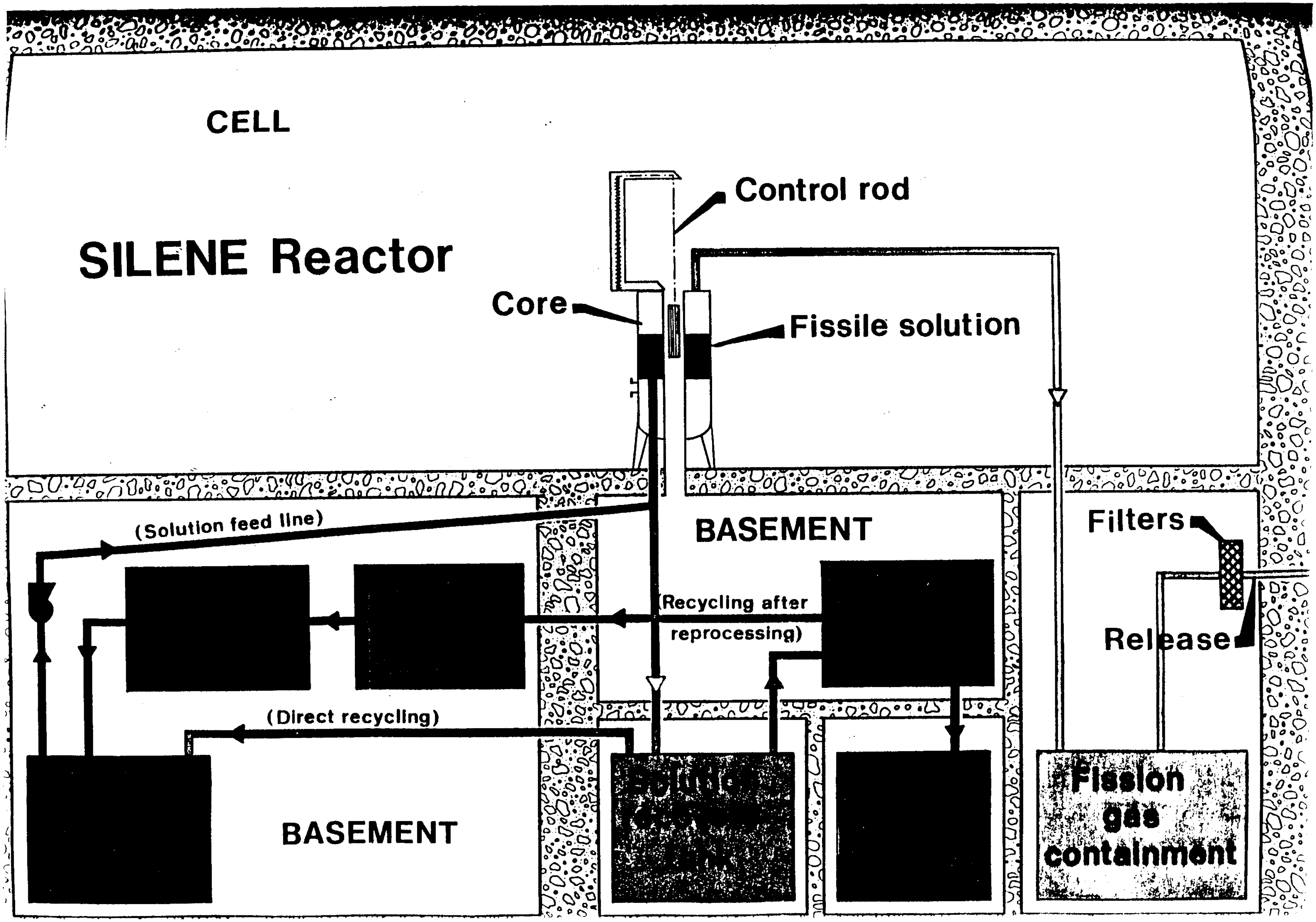
Ref. 8 F. BARBRY, "Dosimetry of neutron and gamma radiation in the CRAC ans SILENE criticality accident study program
Rapport SRSC n° 205, 1991

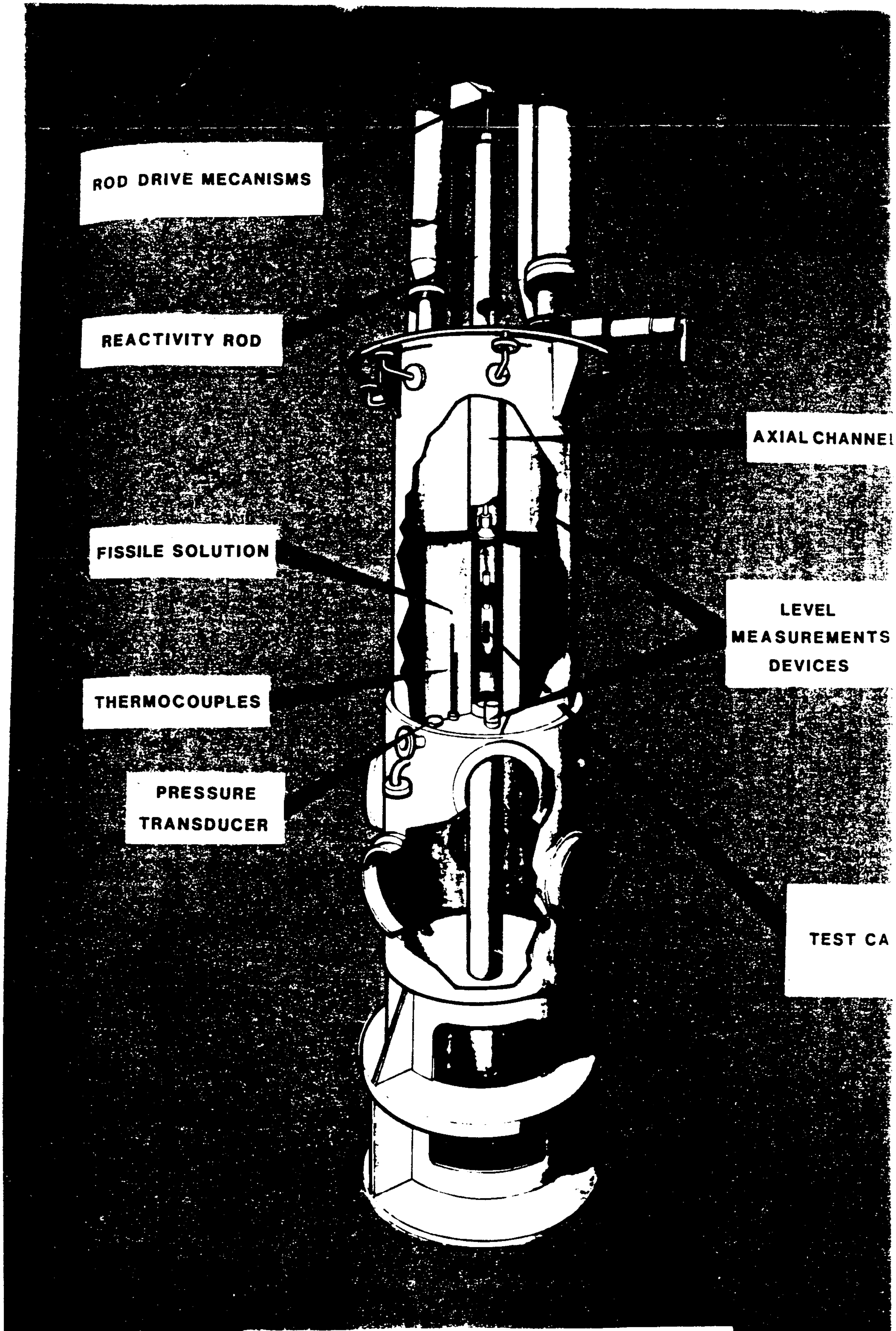
Liste des tableaux de résultats des expériences SILENE

Figures



1 Cœur
2.Ecrans
3.Stockages solution avant
4.Stockage solution après expéri
5.Cuve de confinement des gaz
6.Boîte à gants de prise d'échantillons
7.Boîte à gants d'extraction (retraitement)
8.Stockages des produits de fission
9.Cellule
10.Sous cellule n°4
11.Sous cellule n°3
12.Salle de contrôle
13.Salle calculateur
14.Dispositif d'exercices d'intervention


CELL
SILENE Reactor
Control rod
Core
Fissile solution
(Solution feed line)
BASEMENT
Filters
(Recycling after
reprocessing)
Release
(Direct recycling)
BASEMENT
Fission
gas
containment



Cutaway view of SILENE REACTOR

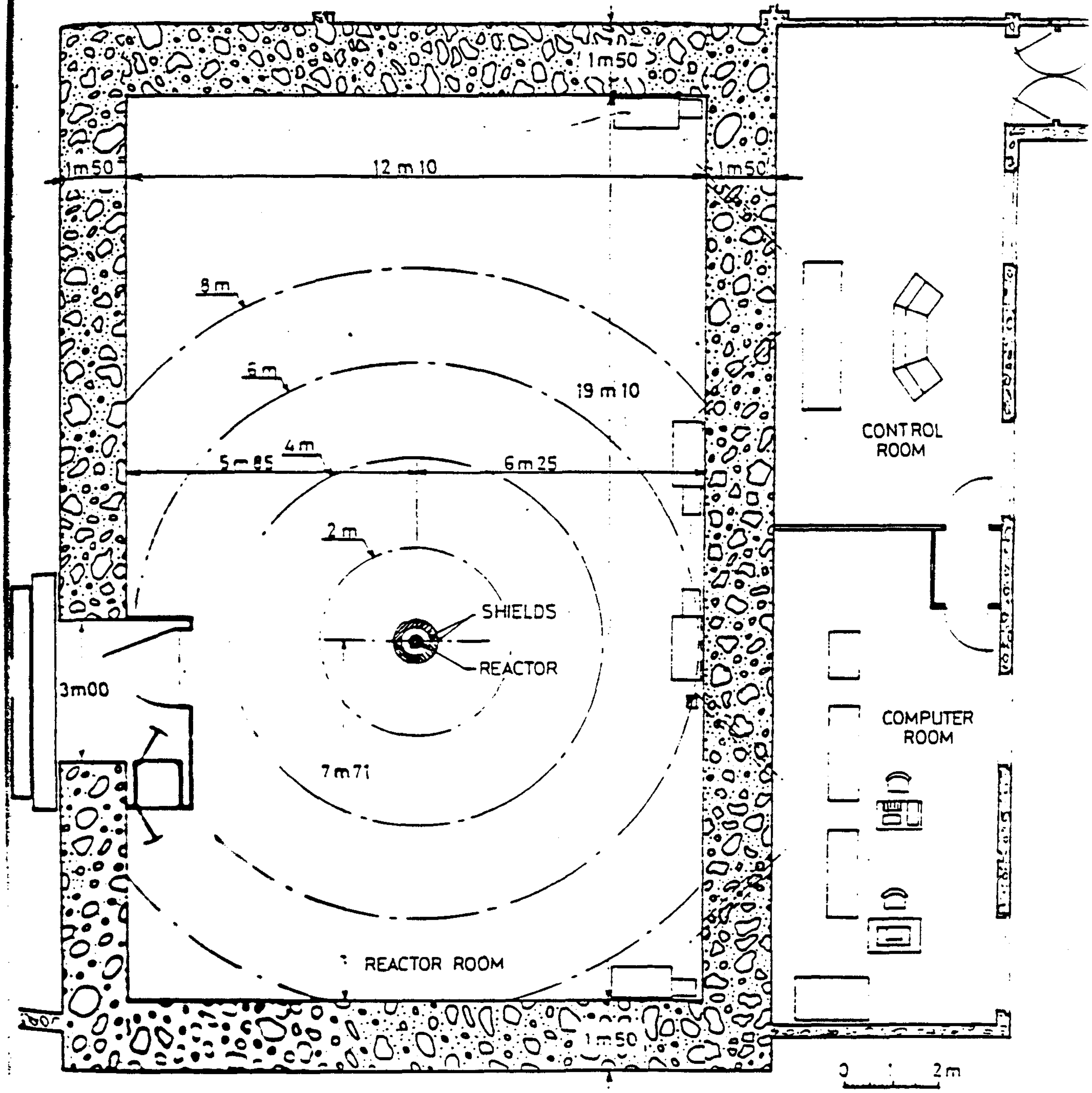


Fig. 4 - SILENE
Reactor diagram building

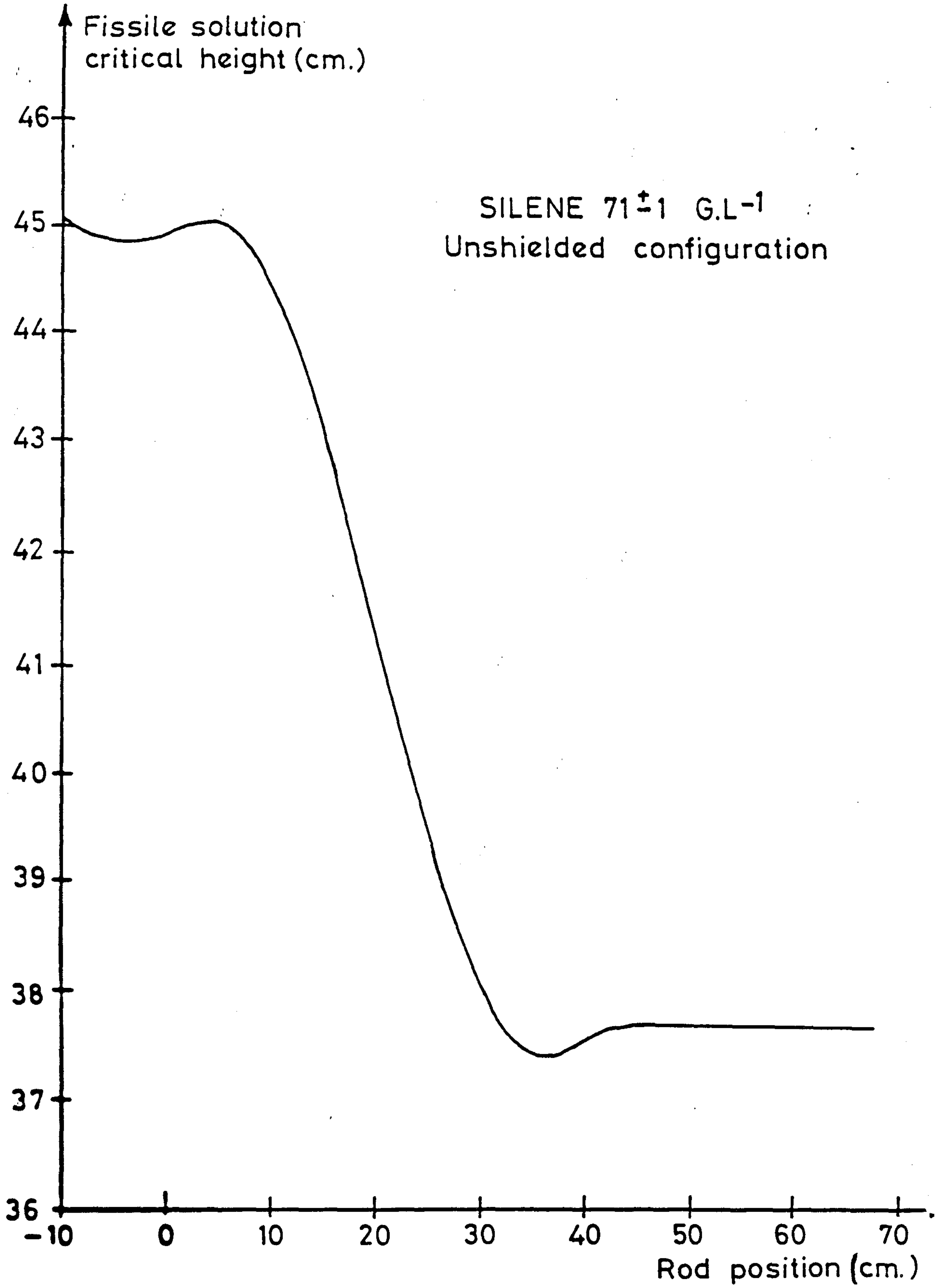
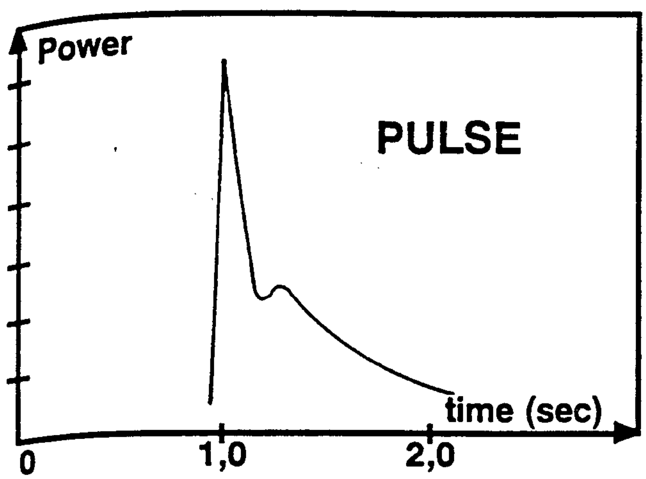


Fig.5 Fissile solution critical height as a function of Cd. rod position.

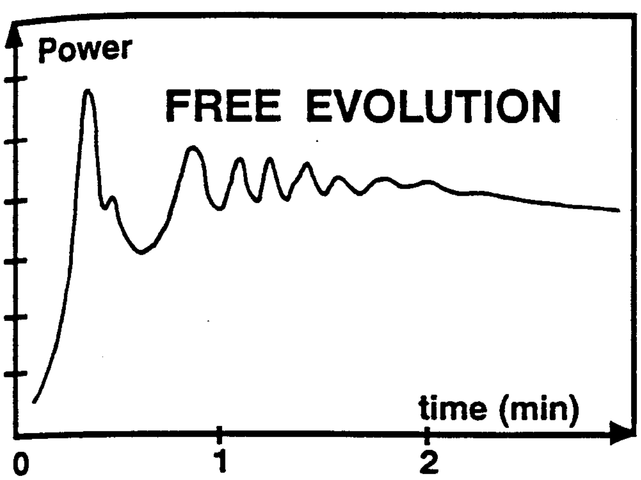


PEAK POWER
$\leqslant$ 3,3.10^{19} fissions.s^{-1}
(1000 Mégawatts)

ENERGY
$\leqslant$ 2.10^{17} fissions.

DOUBLING TIME
$\geqslant$ 1,5 ms

PEAK WIDTH
$\geqslant$ 6 ms

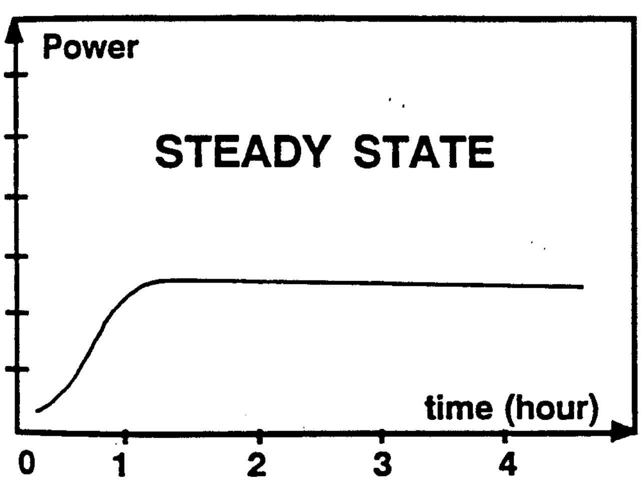


1st PEAK POWER
$\leqslant$ 2.10^{17} fissions.s^{-1}

1st PEAK ENERGY
$\leqslant$ 5.10^{16} fissions.

TOTAL ENERGY
$\leqslant$ 5.10^{17} fissions.

DOUBLING TIME
$\geqslant$ 23 ms



1/100 WATT < Puissance < 10 kwatts

DURATION
Plusieurs heures

TOTAL ENERGY
$\leqslant$ 5.10^{17} fissions

Fig 6 - **SILENE OPERATING MODES**

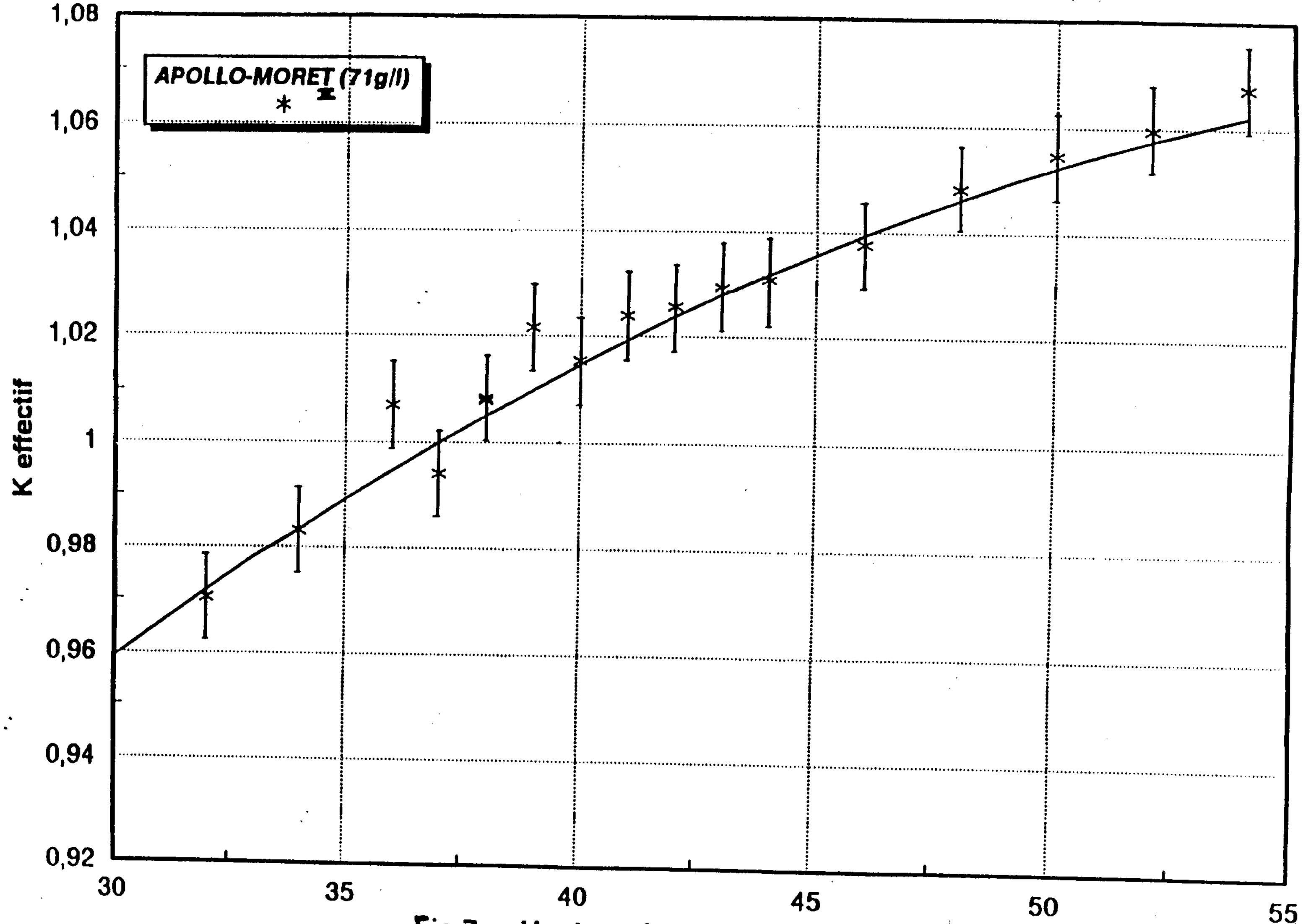


Fig 7. Hauteur de solution (cm)

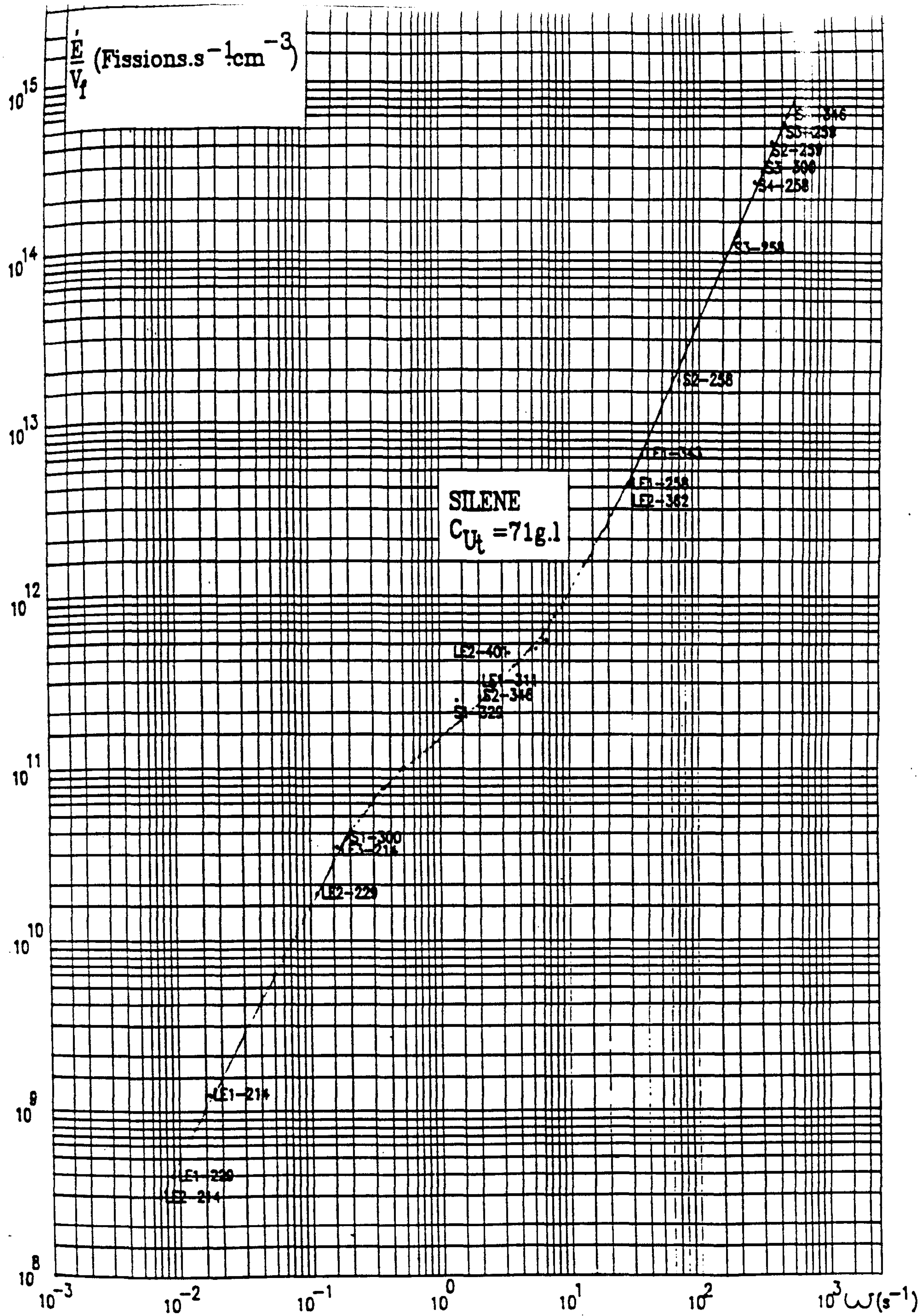


Figure 8 - Relation Beetwen the Specific Power and the Reciprocal Period

SILENE

Unshielded configuration

$C_{U_t} \cong 71 \text{ g.l}^{-1}$

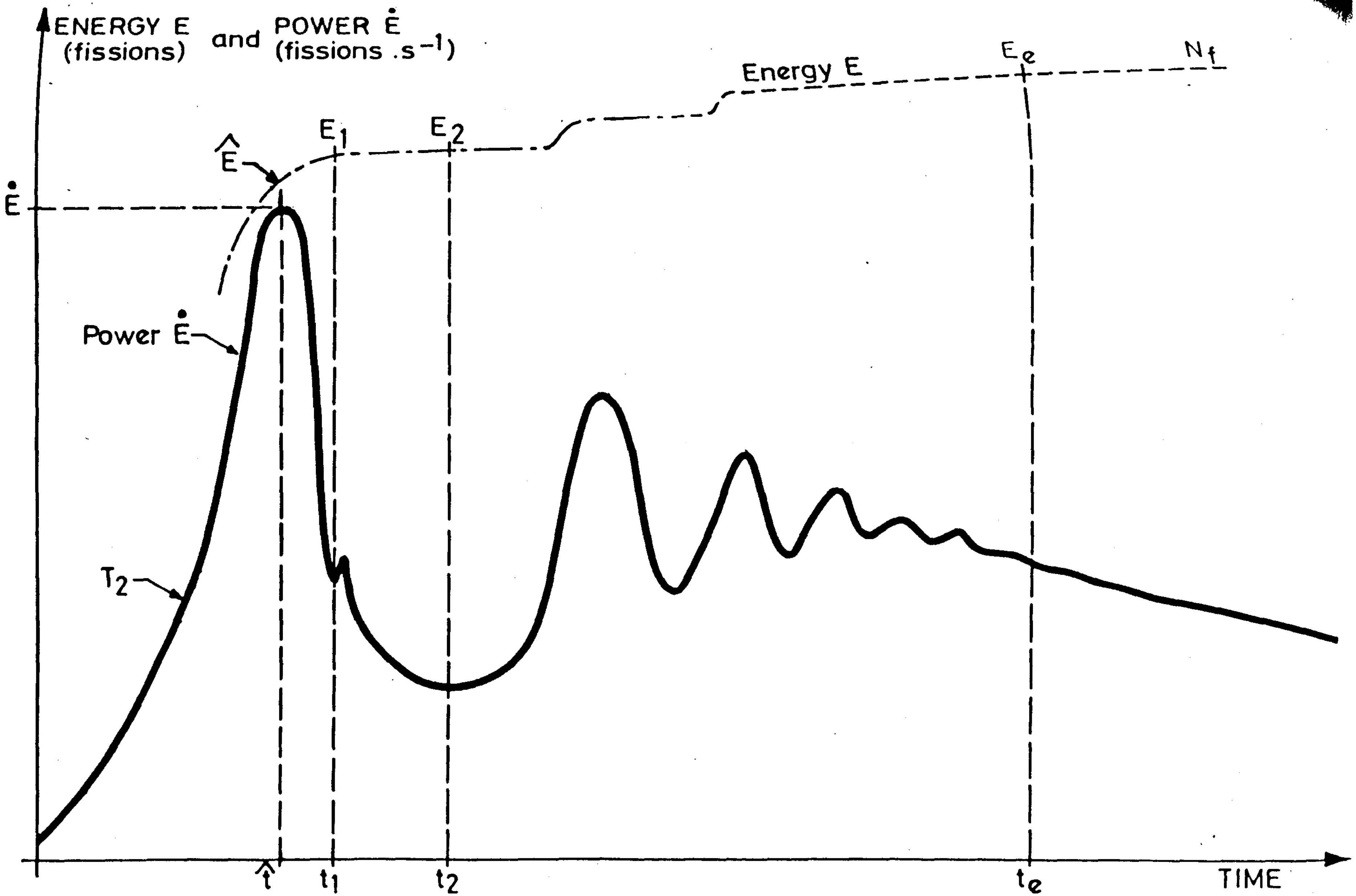
List of reference experiments

SYMBOLS USED

CU_t	Total uranium concentration (in $g.l^{-1}$) (93 % en ^{235}U enriched uranium)
H_f	Final height of solution (cm)
V_f	Final volume (in liters)
ΔH	Solution addition beyond critical height
N_f	Total number of fissions
Δk_p	Total potential reactivity addition in the core
$\Delta keff_1$	Effective reactivity present at the first peak
$\Delta\theta$	Mean rise in temperature of the fissile solution at the end of the experiment (in °C), θ_i designating the initial temperature and θ_f the temperature reached at the equilibrium stage t_e
T_2	Doubling time of power rise (in s)
ω	Reciprocal of period (in s^{-1})
$\dot{E}$	Maximum power at the top of the first peak (in fissions/s)
$\hat{E}$	Energy integrated up to the maximum power of the 1st peak
Δp	Dynamic pressure wave on the core tank bottom during the first peak (relative value in bars)
E_{p1}	Energy integrated up to the botton of the first peak (in fissions)
E_{p2}	Energy integrated during the 1st peak (in fissions)
t_{eq}	Time when equilibrim of solution temperature is reached
E_{eq}	Energy integrated up to t_{eq}

Duration : duration of the experiment

Neutron source : oui = yes   no = non indicates the presence of an external neutronsource (100 mCi Am-be)



TYPICAL CRITICALITY EXCURSION IN SOLUTION

SILENE

SLOW KINETICS EXPERIMENTS $\Delta k_p \leq \beta$

NUMBER	$C_{u\,g/l}$	$H_{c\,cm}$	ΔH_{mm}	$H_{f\,cm}$	$V_{f\,l}$	1st PEAK								
						$T_{2\,s}$	$\omega_{s^{-1}}$	$\hat{t}_s$	$\dot{E}$ fissions $_{s^{-1}}$	$\hat{E}$ fissions	E_{P_2} fissions	ΔP_{bar}	$\Delta k_{1\,PCM}$	Δk_{1}
LE3-229	[illegible]	37.2	0.5	37.17	36.1	235	0.003	3900	1.4 10^{12}	1.1 10^{15}			28	0.03
LE2-214	71.3	37.9	1	37.85	36.8	98.8	0.007	2100	1.2$10^{13}$	4.3 10^{15}			59	0.07
LE1-229	71.5	37.2	1	37.27	36.2	80	0.0087	1900	1.5 10^{13}	5.0 10^{15}			70	0.08
LE1-214	71.3	37.9	2	38.08	36.9	43.8	0.016	980	4.5 10^{13}	1.0 10^{16}			111	0.14
LE2-229	71.5	37.2	6.5	37.75	36.6	6.2	0.112	220	7.1 10^{14}	1.9 10^{16}			333	0.42
LE3-214	71.3	37.9	7	38.56	37.4	4.2	0.165	140	1.2 10^{15}	1.8 10^{16}			390	0.49
S1-300	70.8	37.36	8.0	38.16	37.2	3.8	0.182	110	1.3 10^{15}	2.2 10^{16}			405	0.51
S1-329	71.9	37.17	13.3	38.49	37.34	0.430	1.6	14.5	8.4 10^{15}	1.6 10^{16}	4.8 10^{16}		682	0.86
S2-346	70.9	36.82	13.3	38.15	37.00	0.345	2.0	12.8	8.7 10^{15}	1.7 10^{16}	3.7 10^{16}		700	0.88
S2-300	70.8	37.36	15.5	38.91	37.74	0.130	5.3	9.5	1.7 10^{16}	1.3 10^{16}	4.2 10^{16}		769	0.97
S1-258	70.5	37.74	15.5	39.29	38.11	0.110	6.3	6.3	1.9 10^{16}	9.9 10^{15}	3.9 10^{16}		779	0.98

NUMBER	$t_{eq\,s}$	E_{eq} fissions	TEMPERATURE $\Theta_{i\,°c}$	$\Delta\Theta_{°c\,max}$	Total Reactivity $\Delta k_{p\,pcm}$	$\Delta k_{\$}$	DURATION	N_f fissions	SOURCE NEUTRONS	CATEGORY	
											f/l
LE3-229	14000	3.1 10^{15}	20	1	28	0.035	14400	3.1 10^{15}	OUI	1	8,59E13
LE2-214	9000	1.1 10^{16}	19	2.2	59	0.074	16200	1.1 10^{16}	OUI	1	2,99E..
LE1-229	2800	1.2 10^{16}	20	2.5	70	0.088	2880	1.2 10^{16}	OUI	1	3,31E..
LE1-214	8000	2.0 10^{16}	19	4	111	0.14	16200	2.4 10^{16}	OUI	1	6,E..
LE2-229	6000	5.6 10^{16}	20	11.5	333	0.42	14400	7.5 10^{16}	OUI	1	2,0.E16
LE3-214	780	6.3 10^{16}	19	13.5	390	0.49	780	6.3 10^{16}	OUI	1	
S1-300	1000	6.0 10^{16}	22.2	13.7	405	0.51	1100	6.5 10^{16}	OUI	1	
S1-329	37	6.0 10^{16}	21.0	17.0	682	0.98	62	7.7 10^{16}	OUI	2	
S2-346	60	6.4 10^{16}	19.0	19.0	700	0.88	170	8.8 10^{16}	OUI	2	[illegible]
S2-300	60	7.0 10^{16}	21.7	21.7	769	0.97	265	1.1 10^{17}	NON	2	2,91E15
S1-258	60	7.7 10^{16}	21.4	21.4	779	0.98	380	1.1 10^{17}	NON	2	

$\overline{C_0} = 71,15$; $\overline{H_c} = 37,37$

$\overline{V_s} =$

SILENE

"PULSE" OPERATION EXPERIMENTS $\Delta k >> \beta$

Table -2-

NUMBER	$C_{U\ g/l}$	$H_{c\ cm}$	ΔH_{mm}	$H_{f\ cm}$	$V_{f\ l}$	1st PEAK									
						$T_{2\ s}$	$\omega_{s^{-1}}$	t_s	$\dot{E}_{fissions\ s^{-1}}$	$\hat{E}_{fissions}$	E_{p_1}	E_{p_2}	ΔP_{bar}	$\Delta k_{1\ PCM}$	$\Delta k_{1\ S}$
S2-258	70.5	37.74	21.0	39.84	38.6	0.010	68.6	1.526	$7.1\ 10^{17}$	$1.8\ 10^{16}$	$4.5\ 10^{16}$	$4.7\ 10^{16}$		1046	1.32
S3-258	70.5	37.74	28.1	40.55	39.3	0.0038	181	1.432	$4.9\ 10^{18}$	$5.4\ 10^{16}$	$8.1\ 10^{16}$	$8.4\ 10^{16}$	1	1458	1.84
S1-362	69.9	37.57	46.0	42.17	40.9	0.00391	177	3.405	$5.3\ 10^{18}$	$5.6\ 10^{16}$	$8.5\ 10^{16}$	$8.5\ 10^{16}$	1.05	1420	1.79
S4-258	70.5	37.74	32.0	40.94	39.7	0.0028	249	1.798	$9.1\ 10^{18}$	$7.0\ 10^{16}$	$1.0\ 10^{17}$	$1.0\ 10^{17}$	1.9	1696	2.14
S3-300	70.8	37.36	36.0	40.96	39.7	0.00243	285	1.314	$1.1\ 10^{19}$	$6.6\ 10^{17}$	$1.0\ 10^{17}$	$1.0\ 10^{17}$	2.55	1832	2.31
S2-259	70.5	37.38	40.0	41.38	40.1	0.00198	350	1.238	$1.7\ 10^{19}$	$8.2\ 10^{16}$	$1.3\ 10^{17}$	$1.3\ 10^{17}$	3.7	2068	2.6
S4-259	70.5	37.38	44.0	41.78	40.5	0.00192	361	1.193	$1.8\ 10^{19}$	$8.6\ 10^{16}$	$1.3\ 10^{17}$	$1.3\ 10^{17}$	4.4	2108	2.65
S3-259	70.5	37.38	44.0	41.78	40.5	0.00171	405	1.365	$2.1\ 10^{19}$	$7.9\ 10^{16}$	$1.4\ 10^{17}$	$1.4\ 10^{17}$	4.8	2269	2.86
S4-346	70.9	36.81	46.0	41.41	40.2	0.00162	428	1.234	$2.4\ 10^{19}$	$9.8\ 10^{16}$	$1.5\ 10^{17}$	$1.5\ 10^{17}$	5.6	2350	2.96
S1-346	70.9	36.82	46.0	41.42	40.2	0.00162	428	1.170	$2.5\ 10^{19}$	$9.8\ 10^{16}$	$1.5\ 10^{17}$	$1.5\ 10^{17}$	5.6	2350	2.96

NUMBER	$t_{eq\ s}$	$E_{eq\ fissions}$	TEMPERATURE		TOTAL REACTIVITY ADDITION		DURATION	$N_{f\ fissions}$	SOURCE	OBJECTIVES	CATEGORY
			$\Theta_{i\ °C}$	$\Delta\Theta_{°C\ max}$	$\Delta k_{p\ pcm}$	$\Delta k_{p\ S}$					
S2-258	50	$8.8\ 10^{16}$	20.4	28.3	1046	1.32	11220	$1.5\ 10^{17}$	non	Cinétique +rentrée de la barre à t = 7 min	3
S3-258	90	$1.42\ 10^{17}$	20.4	35.7	1458	1.84	420	$1.9\ 10^{17}$	non	Cinétique	3
S1-362	160	$2.6\ 10^{17}$	20	50	2350	2.96	210	$2.8\ 10^{17}$	oui	Salve avec source éjection barre Cd : 20 cm.s⁻¹	4.7
S4-258	90	$1.7\ 10^{17}$	20.5	40.2	1696	2.14	420	$2.3\ 10^{17}$	non	Cinétique	3
S3-300	80	$1.8\ 10^{17}$	22.3	39.9	1832	2.31	120	$2.1\ 10^{17}$	non	Cinétique	3
S2-259	90	$2.1\ 10^{17}$	20.6	47.4	2068	2.6	420	$2.7\ 10^{17}$	non	Cinétique	3
S4-259	90	$2.2\ 10^{17}$	20.8	50.9	2108	2.65	10920	$2.9\ 10^{17}$	oui	Cinétique + rentrée de la barre à t = 7 min	4
S3-259	70	$2.1\ 10^{17}$	20.7	51.1	2269	2.86	420	$2.9\ 10^{17}$	non	Cinétique	3
S4-346	180	$2.9\ 10^{17}$	21.5	53	2350	2.96	180	$2.9\ 10^{17}$	non	Ejection barre Cd rapide 1.5 m.s⁻¹	3.7
S1-346	180	$2.9\ 10^{17}$	21	53	2350	2.96	180	$2.9\ 10^{17}$	oui	Ejection barre Cd rapide 1.5 m.s⁻¹	4.7

Total 7.21E15 · for first peak 3.13E15

SILENE

"FREE EVOLUTION" MODE EXPERIMENTS

NUMBER	$C_{U\,g/l}$	$H_{c\,cm}$	ΔH_{mm}	$H_{f\,cm}$	$V_{f\,l}$	1st PEAK $T_{2\,s}$	$\omega_{s^{-1}}$	$\dot{E}_{fissions\,.\,s^{-1}}$	$\hat{E}_{fissions}$	E_{p_1}	E_{p_2}	ΔP_{bar}	$\Delta k_{1\,PCM}$	$\Delta k_{1\,S}$	$t_{eq\,s}$	$E_{eq\,fissions}$
LE1-362	69.9	37.57	46.0	42.17	40.90	0.136	5.1	$2.0\ 10^{16}$	$9.6\ 10^{15}$	$4.1\ 10^{16}$	$4.4\ 10^{16}$		766	0.95	300	$2.9\ 10^{17}$
LE2-362	69.9	37.57	46.0	42.17	40.90	0.0245	28.3	$1.8\ 10^{17}$	$1.2\ 10^{16}$	$4.5\ 10^{16}$	$4.7\ 10^{16}$		890	1.12	160	$2.6\ 10^{17}$
LE1-311	70.5	37.27	60.0	43.27	42.00	0.38	1.8	$1.3\ 10^{10}$	$2.0\ 10^{16}$	$3.7\ 10^{16}$	$4.6\ 10^{16}$		693	0.87	600	$4.0\ 10^{17}$
LE1-258	70.5	37.74	60.0	43.74	42.43	0.0239	29.0	$1.8\ 10^{17}$	$1.1\ 10^{16}$	$4.2\ 10^{16}$	$4.6\ 10^{16}$		893	1.12	150	$3.0\ 10^{17}$
LE1-273	70.7	37.54	62.0	43.74	42.43	0.025	27.7	$1.7\ 10^{17}$	$1.1\ 10^{16}$	$4.4\ 10^{16}$	$4.6\ 10^{16}$		890	1.12	140	$3.0\ 10^{17}$

NUMBER	TEMPERATURE		TOTAL REACTIVITY		DURATION	$N_{f\,fissions}$	SOURCE NEUTRONS	PARTICULARITY	CATEGORY
	$\Theta_{i\,°C}$	$\Delta\Theta_{°C\,max}$	$\Delta k_{p\,pcm}$	$\Delta k_{p\,S}$					
LE1-362	20	52	2350	2.96	700	$3.1\ 10^{17}$	OUI	vitesse sortie barre Cd 2 mm/s	5.7
LE2-362	20	50	2350	2.96	210	$2.8\ 10^{17}$	OUI	vitesse sortie barre Cd 9.5 mm/s	5.7
LE1-311	20.0	63.4	2770	3.50	660	$4.0\ 10^{17}$	OUI	vitesse sortie barre Cd 2.7 mm/s	5
LE1-258	20.2	62.9	2720	3.42	500	$3.9\ 10^{17}$	OUI	vitesse sortie barre Cd 1 cm/s	5
LE1-273	21	63	2820	3.55	1300	$4.6\ 10^{17}$	OUI	Exercice Intervention/Phase post-accidentelle + redémarrage	5

1.08E16

SILENE

"BOILING" TYPE EXPERIMENTS

NUMBER	$C_{U\ g/l}$	$H_{c\ cm}$	ΔH_{mm}	$H_{f\ cm}$	$V_{f\ l}$	1st PEAK								
						$T_{2\ s}$	$\omega\ s^{-1}$	$\dot{E}_{fissions\ s^{-1}}$	$\hat{E}_{fissions}$	$E_{p_1\ fissions}$	$E_{p_2\ fissions}$	ΔP_{bar}	$\Delta k_{1\ PCM}$	$\Delta k_{1\ \$}$
LE1-175	71.4	36.79	90	45.79	44.41	0.015	46	$4.2\ 10^{17}$	$1.7\ 10^{17}$	$4.2\ 10^{16}$	$4.6\ 10^{16}$		960	1.21
LE1-176	69.8	38.07	114.9	49.56	48.07	0.016	43	$4.5\ 10^{17}$	$1.8\ 10^{16}$	$3.7\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE2-176	69.8	38.07	139.9	52.06	50.49	0.018	38	$4.1\ 10^{17}$	$1.7\ 10^{16}$	$3.7\ 10^{16}$	$5.6\ 10^{16}$		930	1.17
LE2-343	70.6	37.1	140	51.1	49.57	0.016	42.5	$3.8\ 10^{17}$	$1.6\ 10^{16}$	$3.2\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE1-281	70.9	37.42	170	54.42	52.79	0.017	41	$4.2\ 10^{17}$	$1.7\ 10^{16}$	$3.8\ 10^{16}$	$5.4\ 10^{16}$		940	1.18

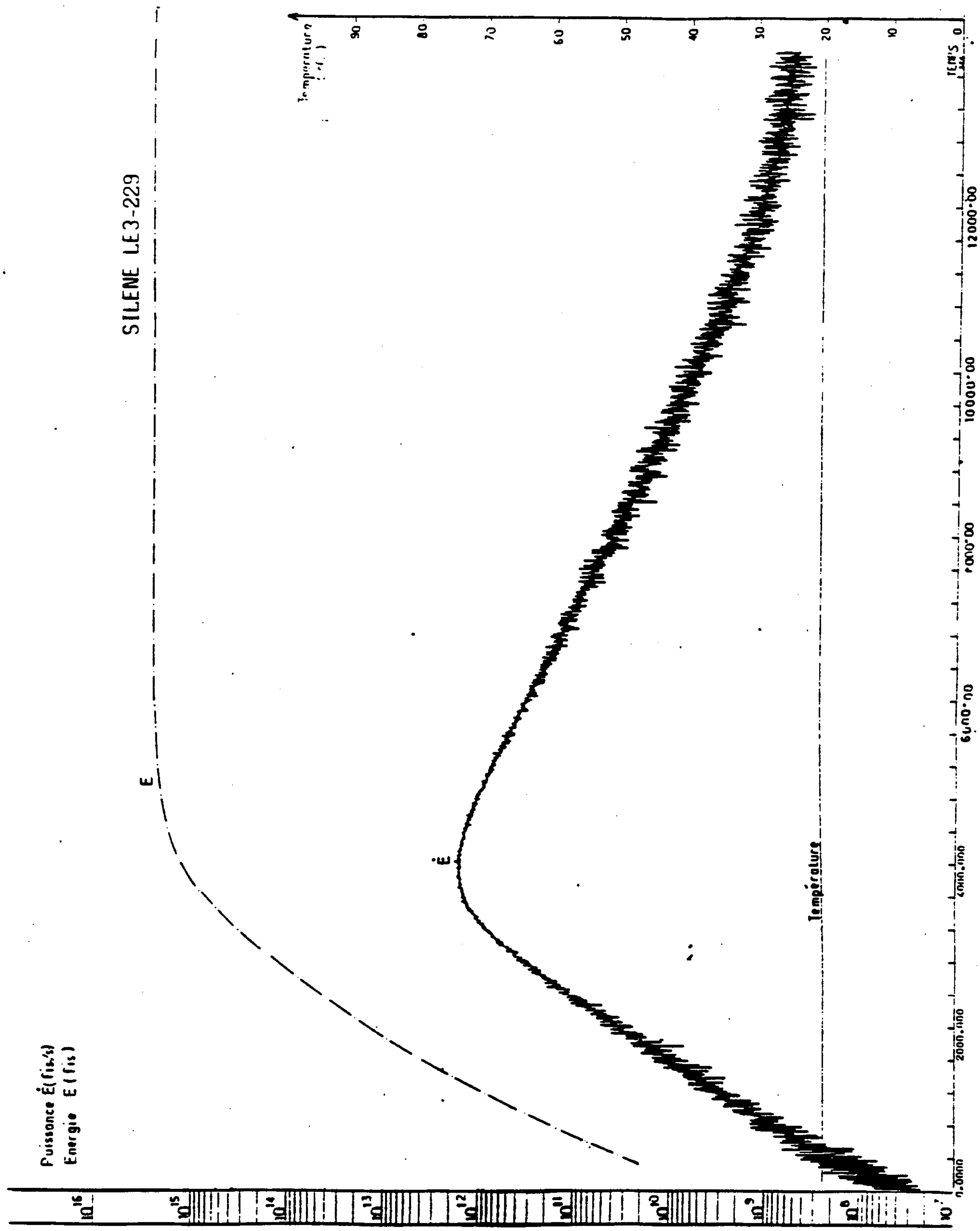
NUMBER	TEMPERATURE		TOTAL REACTIVITY		DURATION	$N_{f\ fissions}$	SOURCE	CATEGORY
	$\Theta_{i\ °C}$	$\Delta\Theta_{°C\ max}$	$\Delta k_{p\ pcm}$	$\Delta k_{p\ \$}$				
LE1-175	19.6		4000	5.0	540	$5.4\ 10^{17}$	OUI	
LE1-176	18.8		4100	5.2	720	$6.9\ 10^{17}$	OUI	5.6
LE2-176	18.8		4800	6.0	900	$7.4\ 10^{17}$	OUI	5.6
LE2-343	22.4		5100	6.4	700	$8.7\ 10^{17}$	OUI	5.6
LE1-281	21		5700	7.2	600	$8.6\ 10^{17}$	OUI	5.6

SILENE

SLOW KINETICS EXPERIMENTS $\Delta k_p \leq \beta$

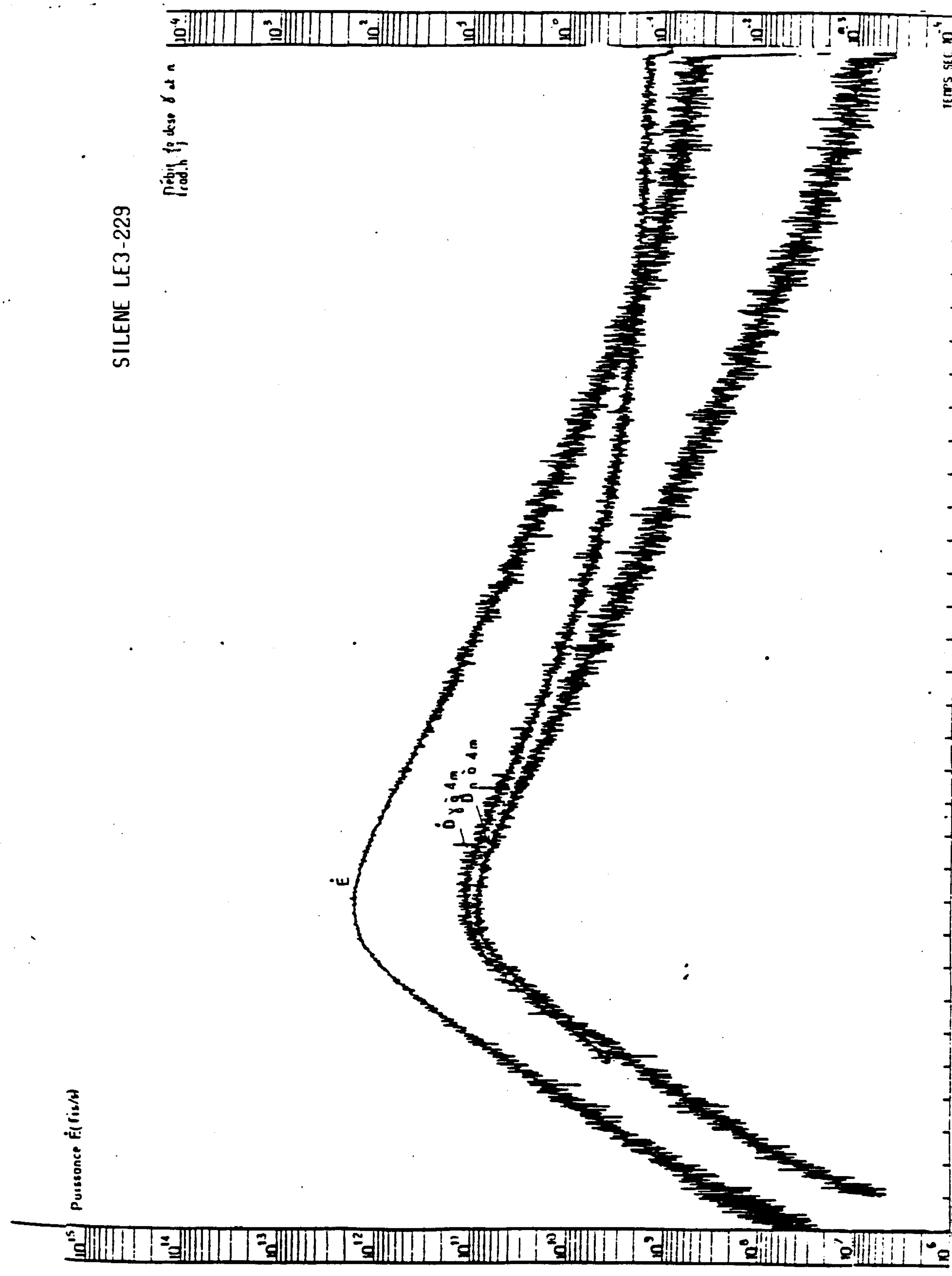
NUMBER	$C_{U_{g/l}}$	$H_{c_{cm}}$	ΔH_{mm}	$H_{f_{cm}}$	V_{f_l}	1st PEAK								
						T_{2_s}	$\omega_{s^{-1}}$	$\hat{t}_s$	$\dot{E}$ $fissions_{s^{-1}}$	$\hat{E}$ $fissions$	E_{P_2} $_{fissions}$	ΔP_{bar}	$\Delta k_{1_{PCM}}$	Δk_{1_S}
LE3-229	71.5	37.2	0.5	37.17	36.1	235	0.003	3900	$1.4\ 10^{12}$	$1.1\ 10^{15}$			28	0.03
LE2-214	71.3	37.9	1	37.85	36.8	98.8	0.007	2100	$1.2 10^{13}$	$4.3\ 10^{15}$			59	0.07
LE1-229	71.5	37.2	1	37.27	36.2	80	0.0087	1900	$1.5\ 10^{13}$	$5.0\ 10^{15}$			70	0.08
LE1-214	71.3	37.9	2	38.08	36.9	43.8	0.016	980	$4.5\ 10^{13}$	$1.0\ 10^{16}$			111	0.14
LE2-229	71.5	37.2	6.5	37.75	36.6	6.2	0.112	220	$7.1\ 10^{14}$	$1.9\ 10^{16}$			333	0.42
LE3-214	71.3	37.9	7	38.56	37.4	4.2	0.165	140	$1.2\ 10^{15}$	$1.8\ 10^{16}$			390	0.49
S1-300	70.8	37.36	8.0	38.16	37.2	3.8	0.182	110	$1.3\ 10^{15}$	$2.2\ 10^{16}$			405	0.51
S1-329	71.9	37.17	13.3	38.49	37.34	0.430	1.6	14.5	$8.4\ 10^{15}$	$1.6\ 10^{16}$	$4.8\ 10^{16}$		682	0.86
S2-346	70.9	36.82	13.3	38.15	37.00	0.345	2.0	12.8	$8.7\ 10^{15}$	$1.7\ 10^{16}$	$3.7\ 10^{16}$		700	0.88
S2-300	70.8	37.36	15.5	38.91	37.74	0.130	5.3	9.5	$1.7\ 10^{16}$	$1.3\ 10^{16}$	$4.2\ 10^{16}$		769	0.97
S1-258	70.5	37.74	15.5	39.29	38.11	0.110	6.3	6.3	$1.9\ 10^{16}$	$9.9\ 10^{15}$	$3.9\ 10^{16}$		779	0.98

NUMBER			TEMPERATURE		Total Reactivity					
	t_{eq_s}	E_{eq} $_{fissions}$	$\Theta_{i\,°c}$	$\Delta\Theta_{°c_{max}}$	$\Delta k_{p_{pcm}}$	Δk_{p_S}	DURATION	N_{f} $_{fissions}$	SOURCE NEUTRONS	CATEGORY
LE3-229	14000	$3.1\ 10^{15}$	20	1	28	0.035	14400	$3.1\ 10^{15}$	OUI	1
LE2-214	9000	$1.1\ 10^{16}$	19	2.2	59	0.074	16200	$1.1\ 10^{16}$	OUI	1
LE1-229	2800	$1.2\ 10^{16}$	20	2.5	70	0.088	2880	$1.2\ 10^{16}$	OUI	1
LE1-214	8000	$2.0\ 10^{16}$	19	4	111	0.14	16200	$2.4\ 10^{16}$	OUI	1
LE2-229	6000	$5.6\ 10^{16}$	20	11.5	333	0.42	14400	$7.5\ 10^{16}$	OUI	1
LE3-214	780	$6.3\ 10^{16}$	19	13.5	390	0.49	780	$6.3\ 10^{16}$	OUI	1
S1-300	1000	$6.0\ 10^{16}$	22.2	13.7	405	0.51	1100	$6.5\ 10^{16}$	OUI	1
S1-329	37	$6.0\ 10^{16}$	21.0	17.0	682	0.98	62	$7.7\ 10^{16}$	OUI	2
S2-346	60	$6.4\ 10^{16}$	19.0	19.0	700	0.88	170	$8.8\ 10^{16}$	OUI	2
S2-300	60	$7.0\ 10^{16}$	21.7	21.7	769	0.97	265	$1.1\ 10^{17}$	NON	2
S1-258	60	$7.7\ 10^{16}$	21.4	21.4	779	0.98	380	$1.1\ 10^{17}$	NON	2

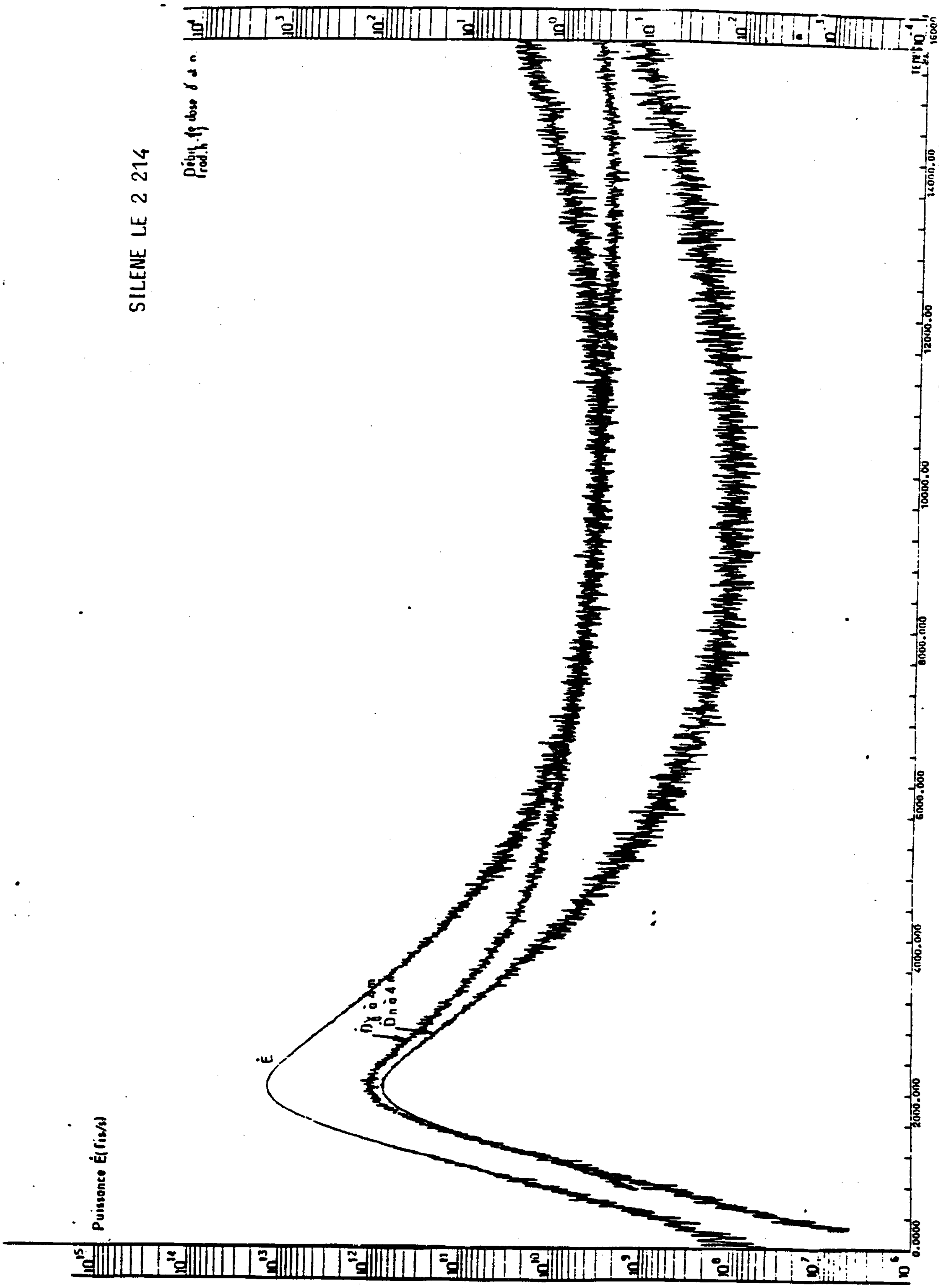


- SILENE 71 g/l configuration sans écran.

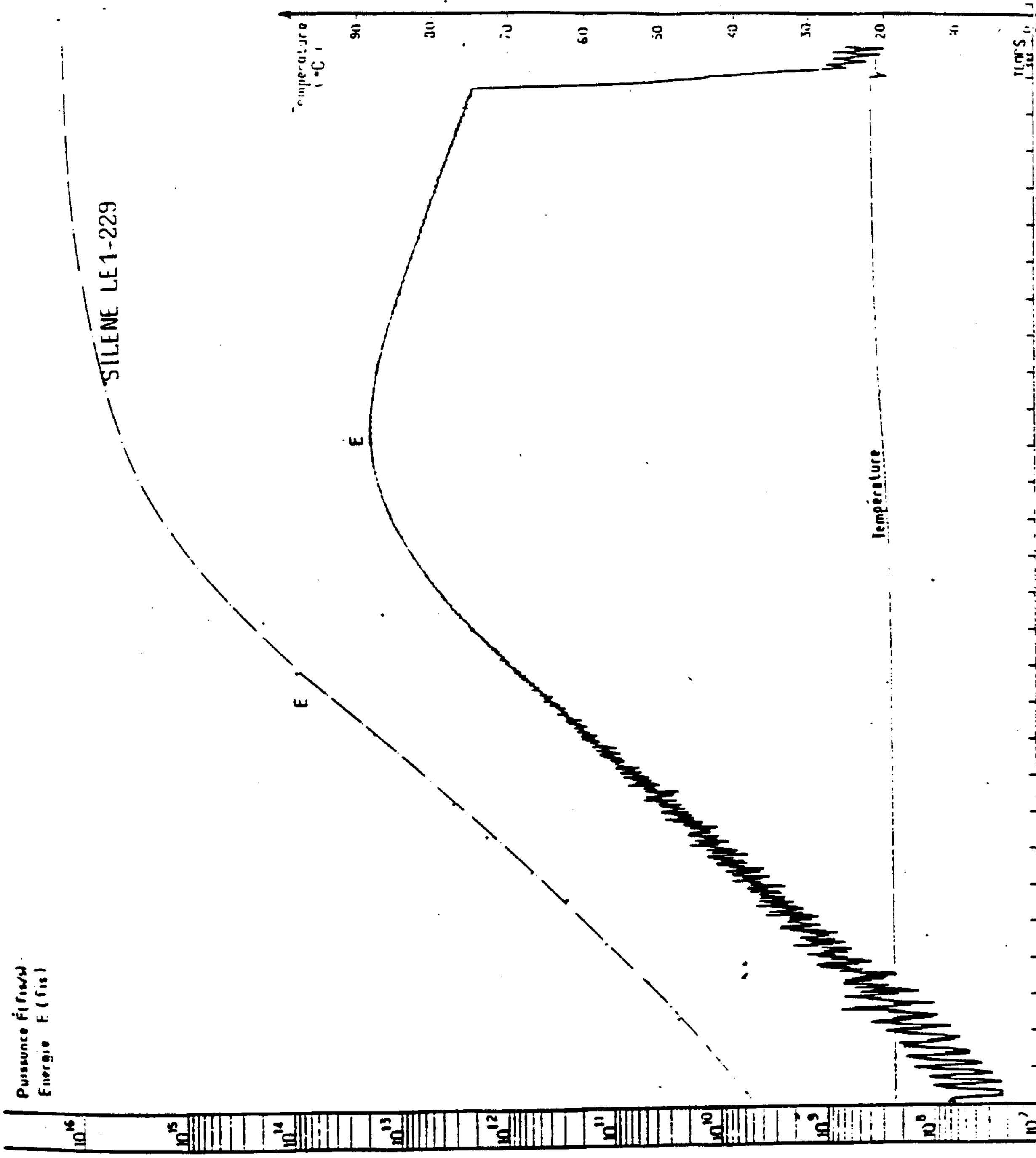
Evolution de la puissance Ė, de l'énergie E et de la température solution.



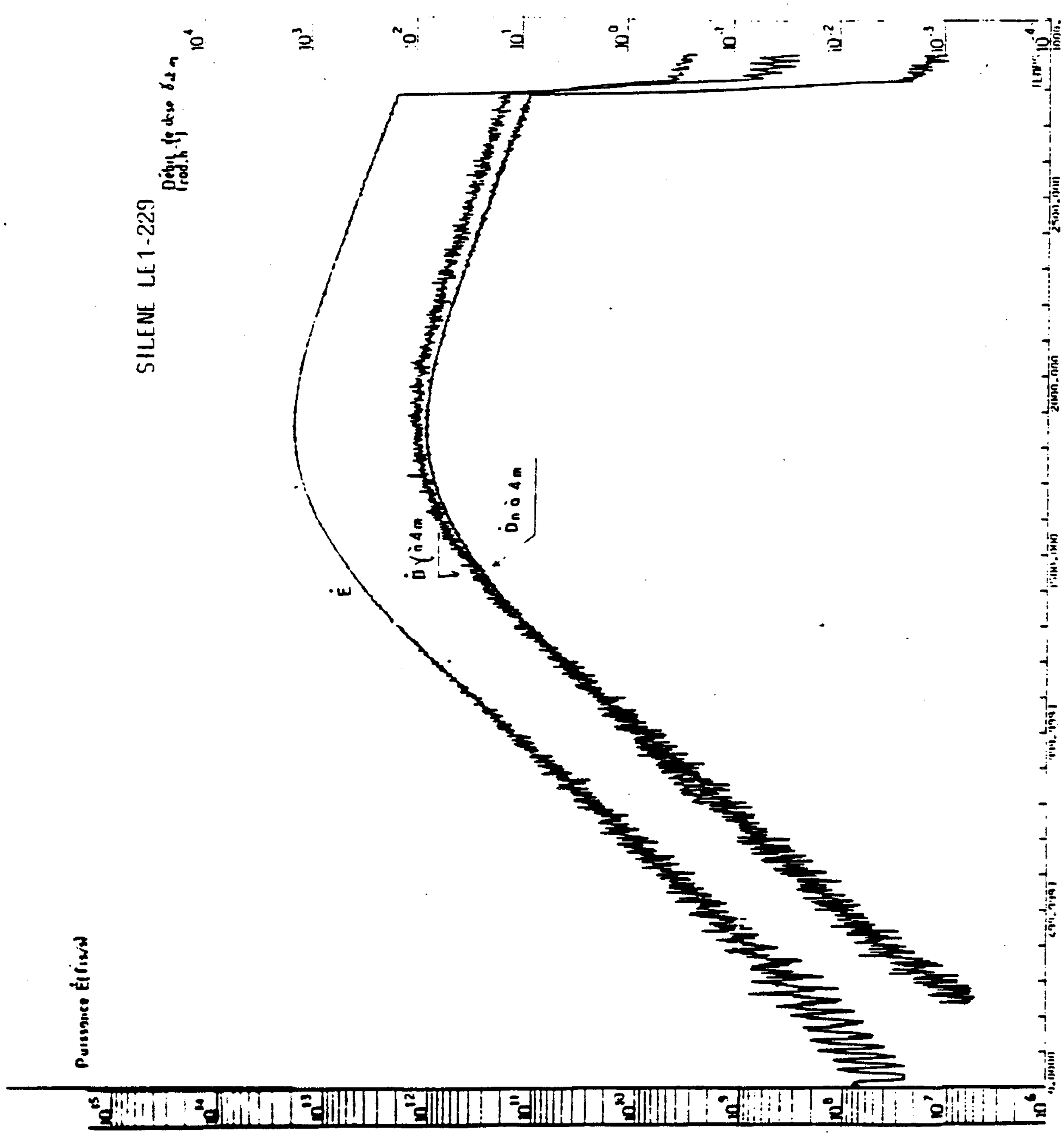
\- SILENE 71 g/l configuration sans écran.
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.



- SILENE 71 g/l configuration sans écran.
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.

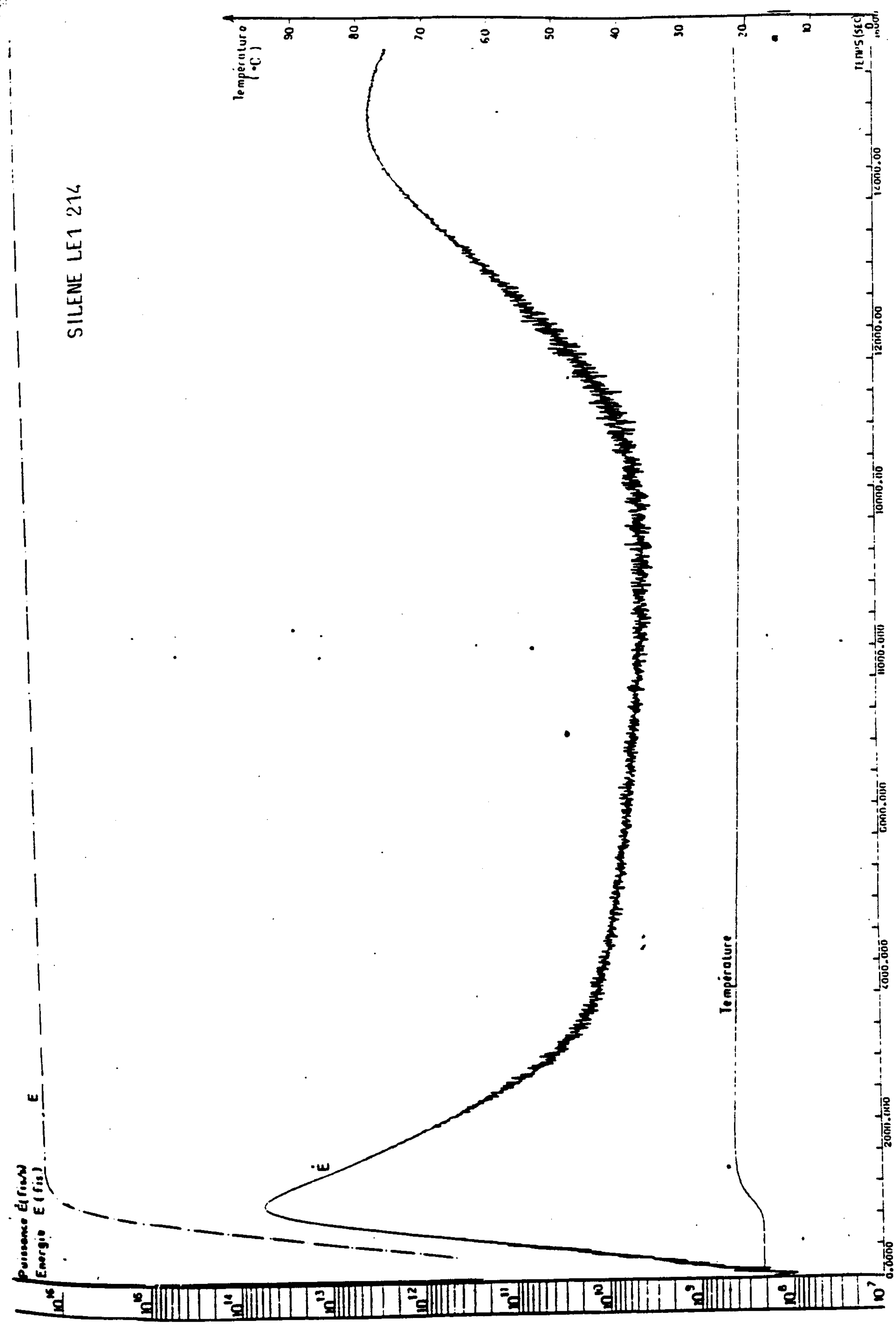


- SILENE 71 g/l configuration sans écran.
  Evolution de la puissance Ė, de l'énergie E et de la température solution

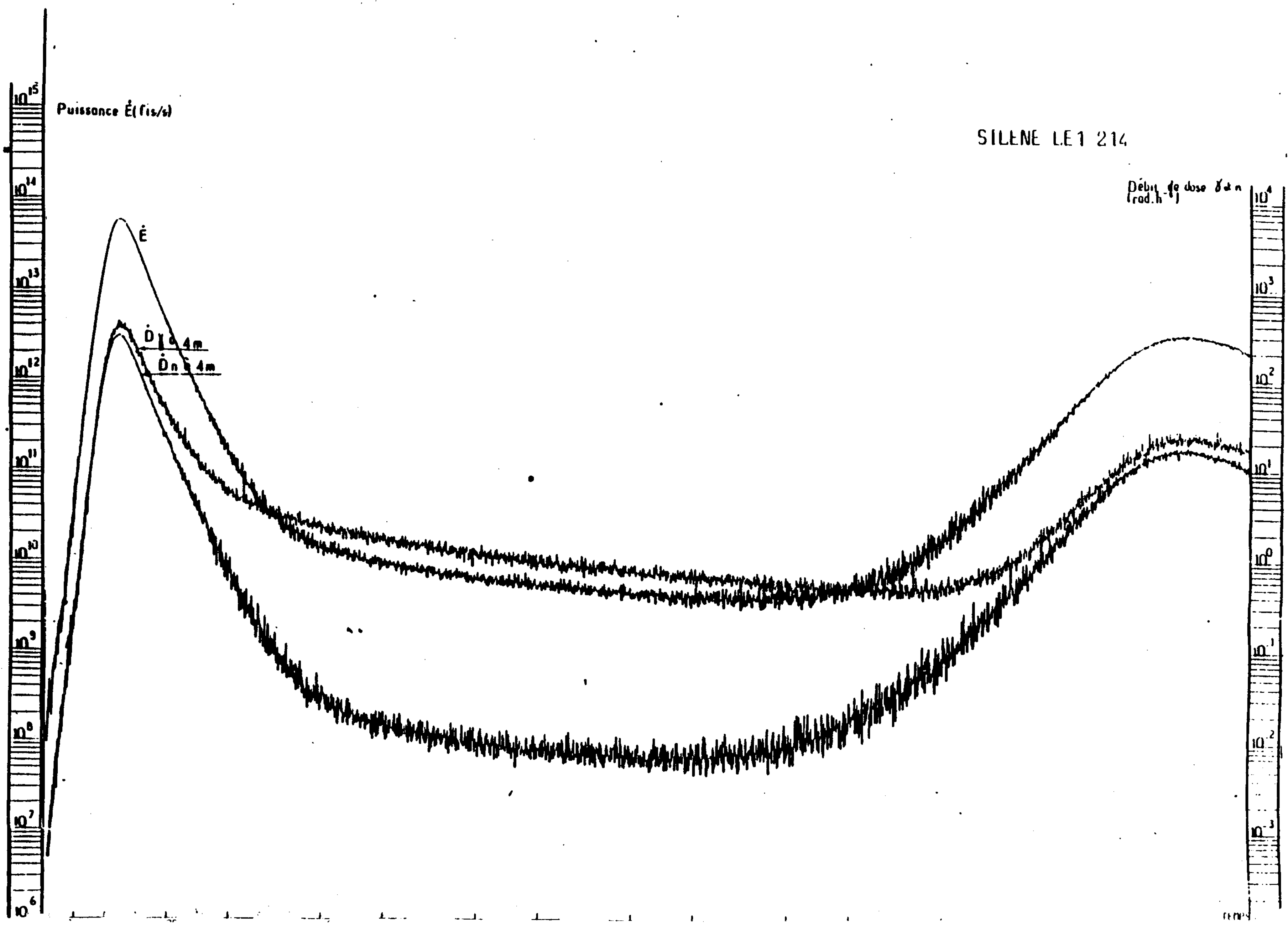


- **SILENE** 71 g/l configuration sans écran.

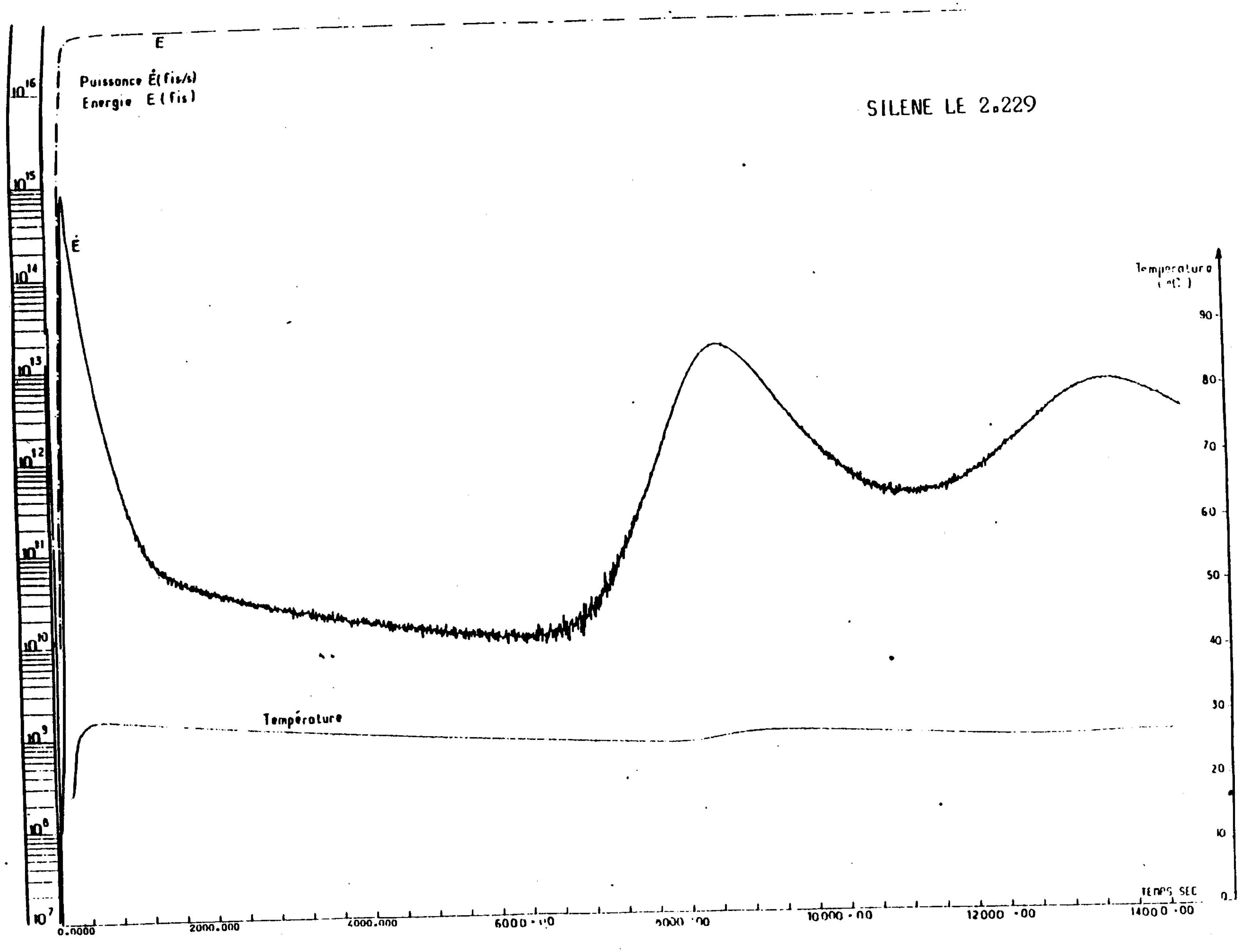
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.



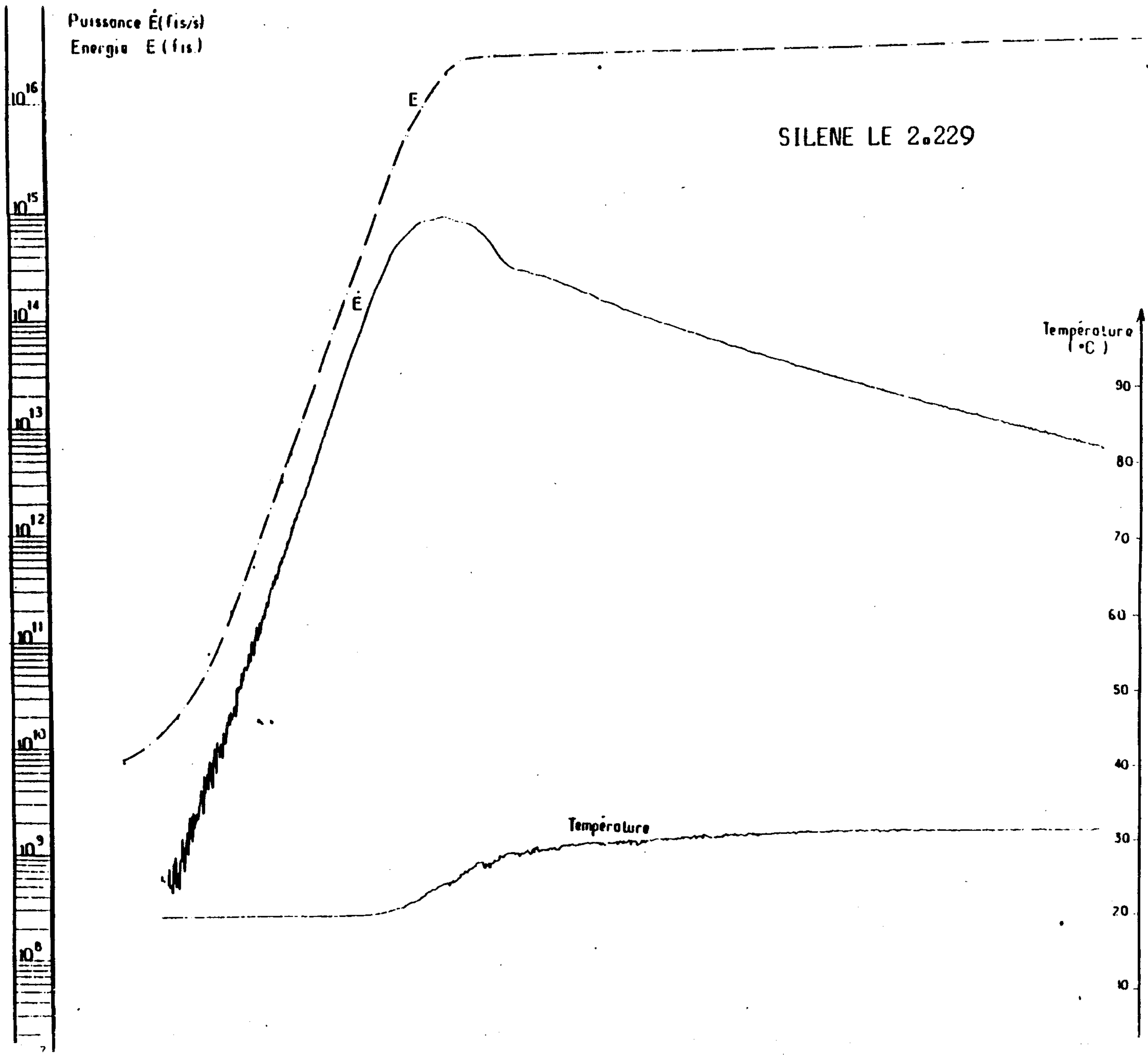
- SILENE 71 g/l configuration sans écran.
Evolution de la puissance É, de l'énergie E et de la température solution



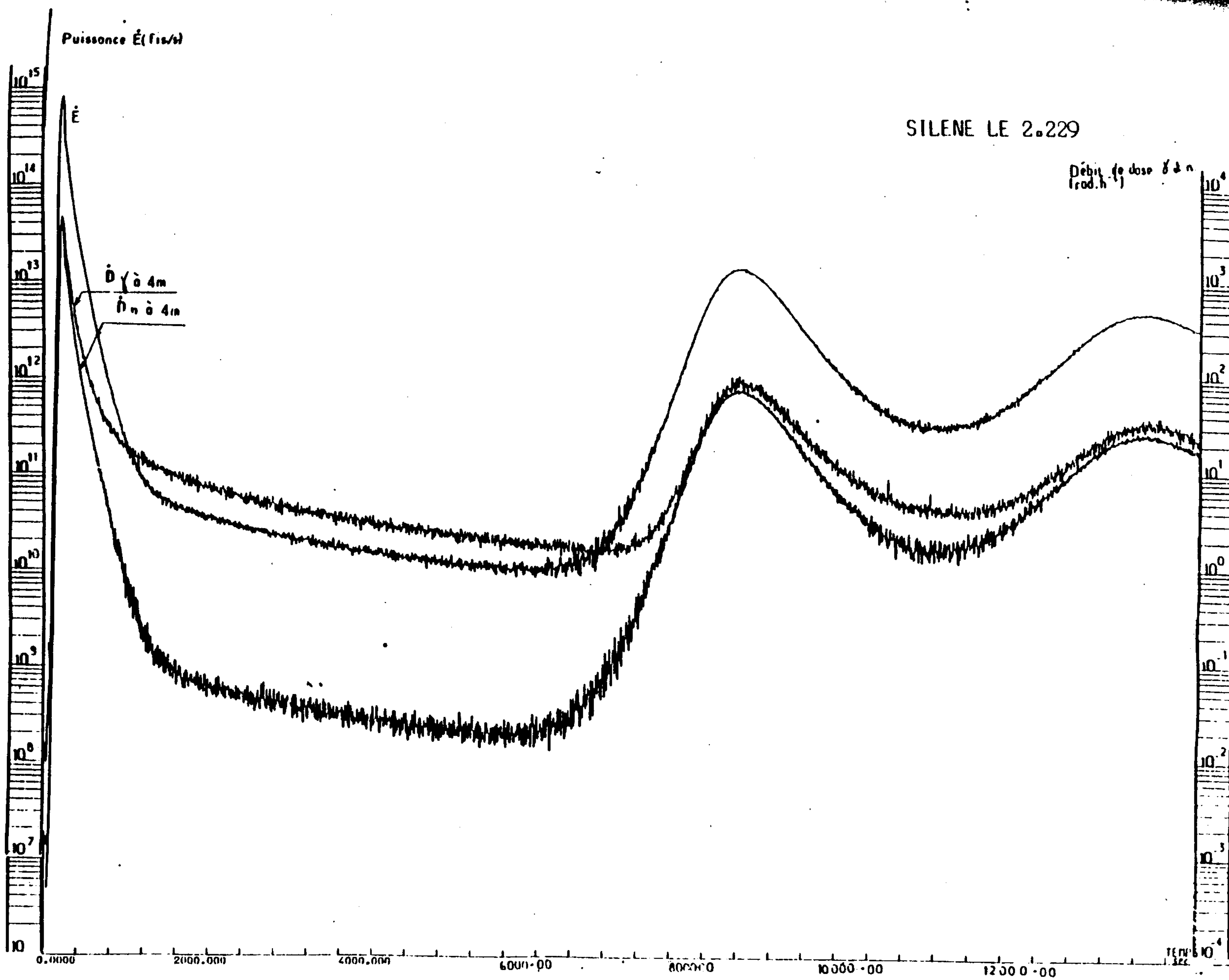
- SILENE 71 g/l configuration sans écran.
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.



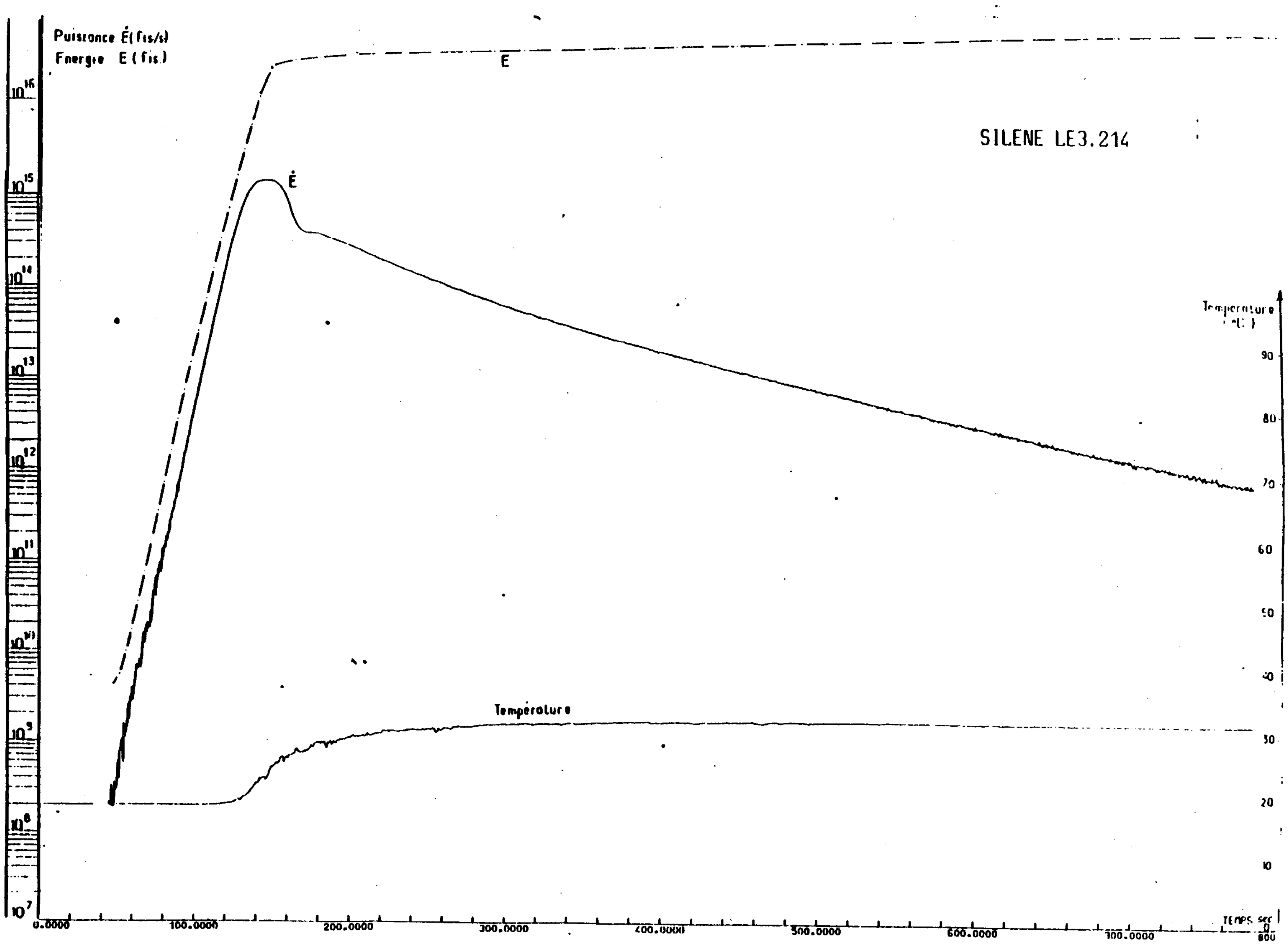
- SILENE 71 g/1 configuration sans écran.
Evolution de la puissance Ė, de l'énergie E et de la température solution.



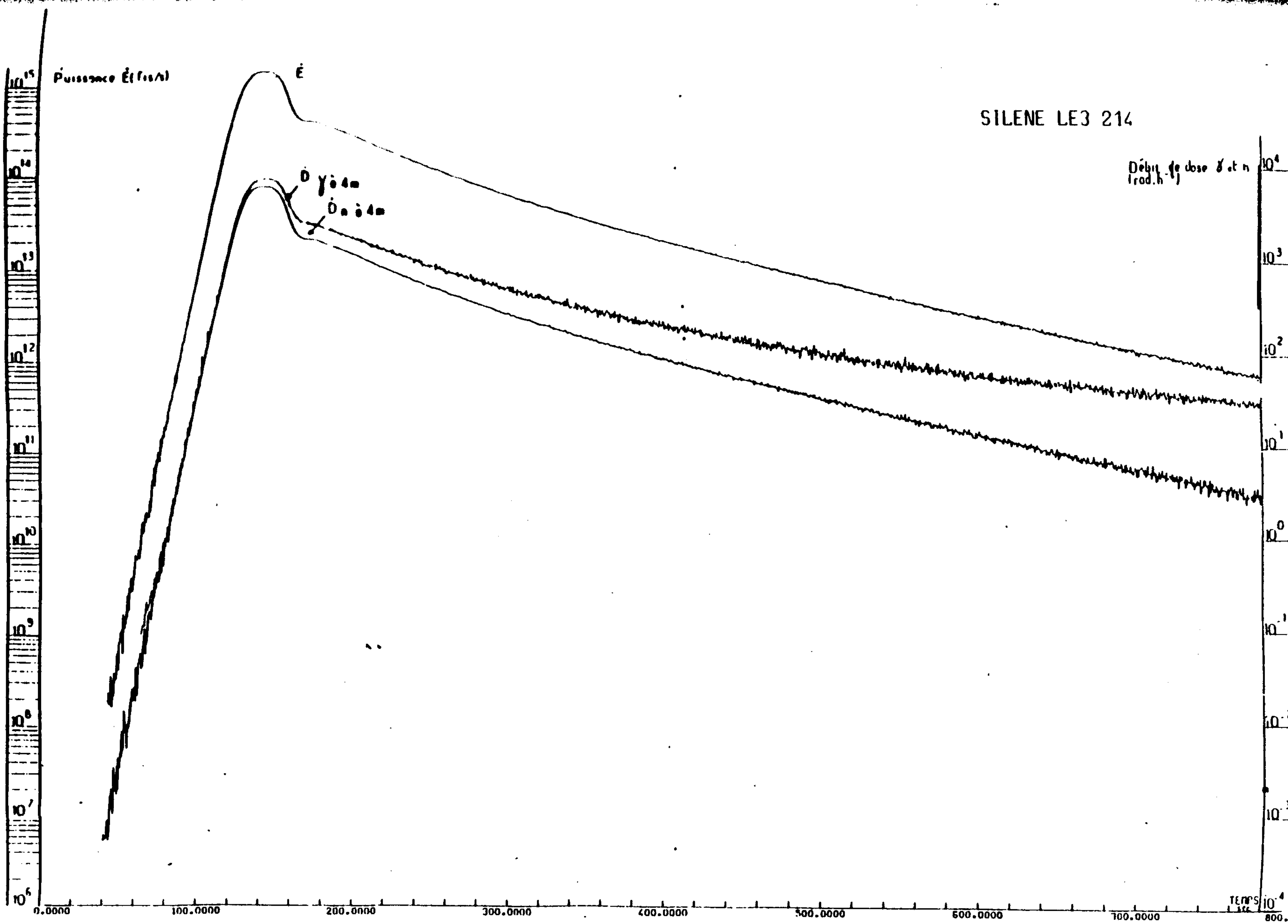
- SILENE 71 g/l configuration sans écran.
Evolution de la puissance Ė, de l'énergie E et de la température solution.



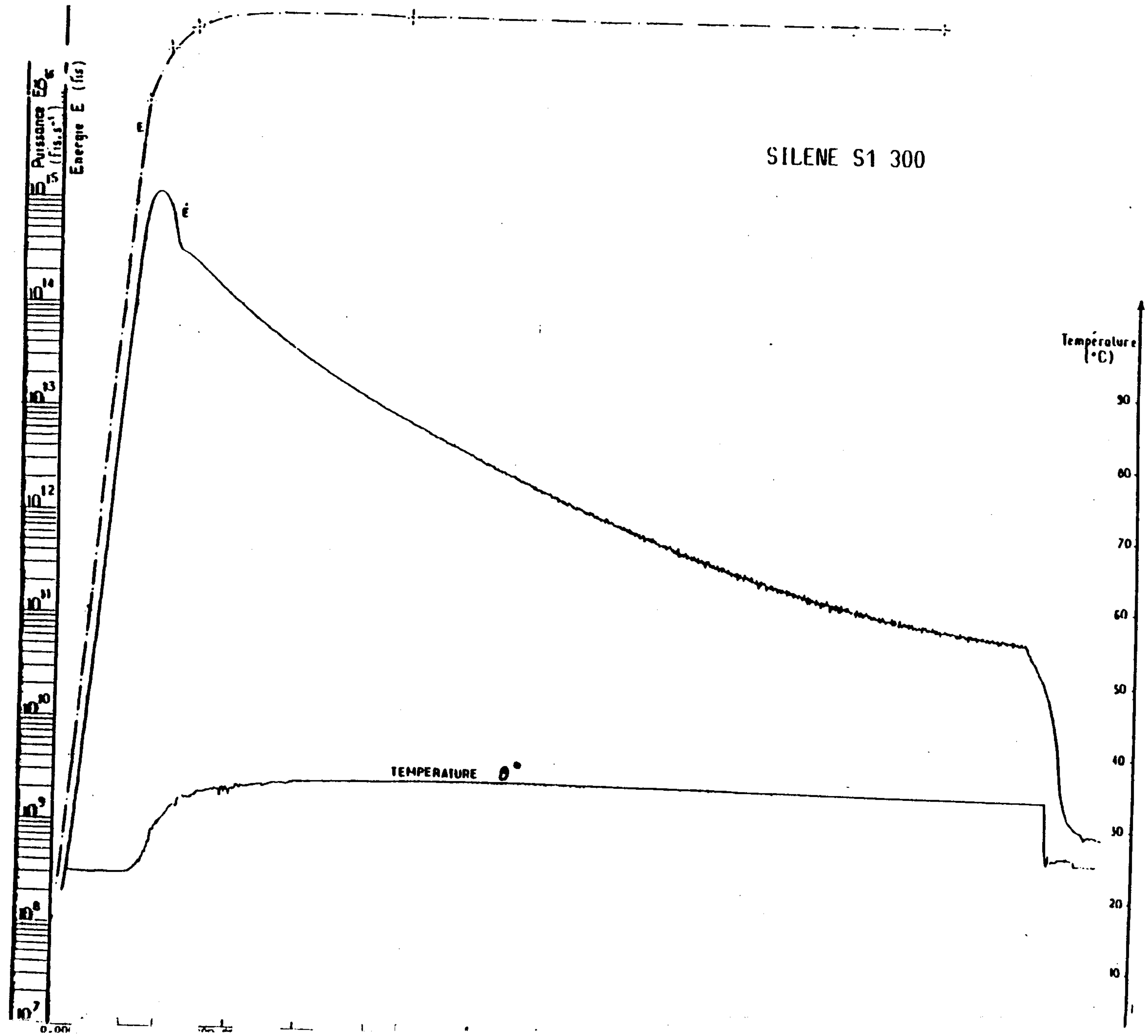
- SILENE 71 g/l configuration sans écran.
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.



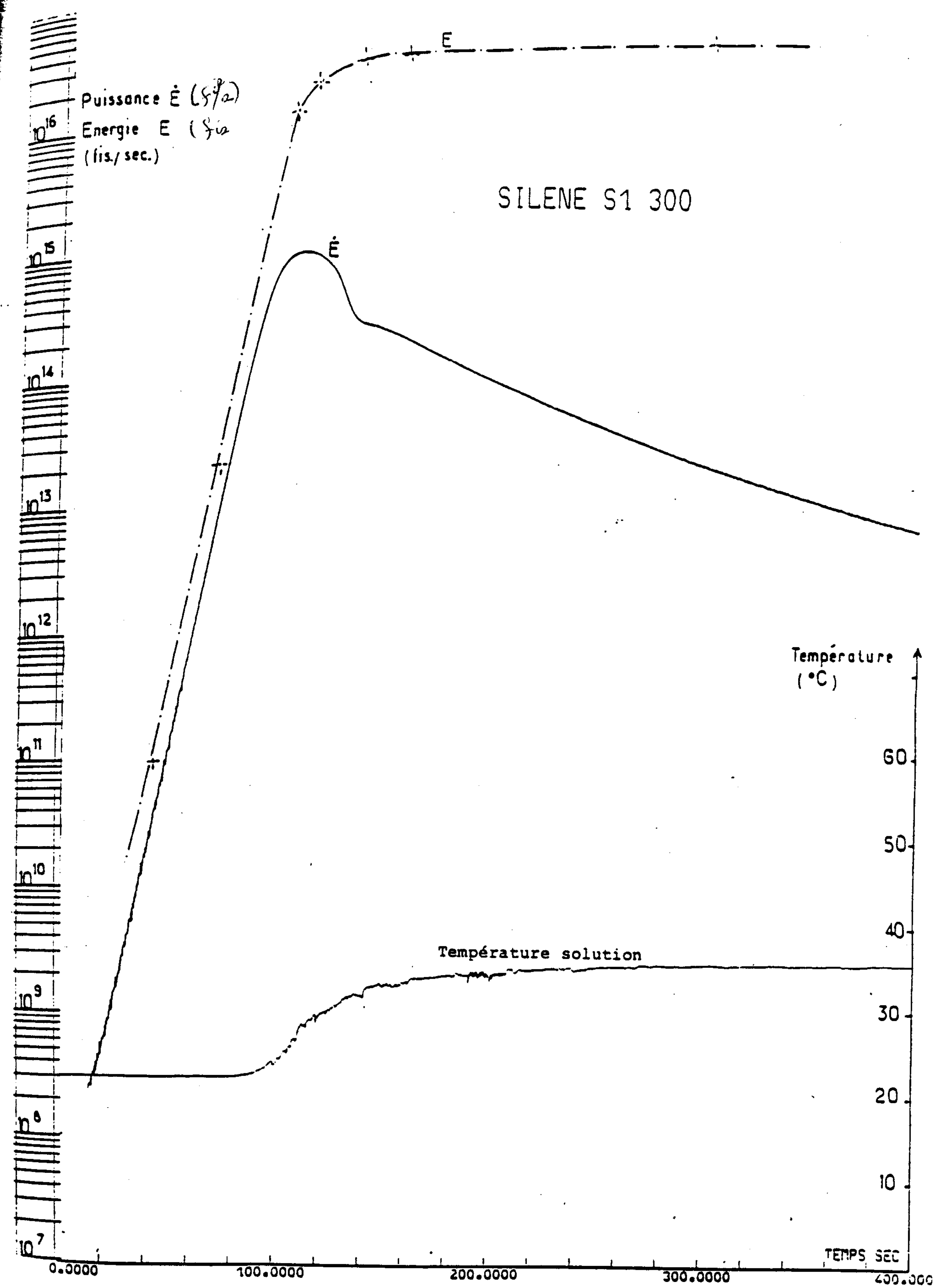
SILENE 71 g/l configuration sans écran.
Evolution de la puissance Ė, de l'énergie E ét de la température solution



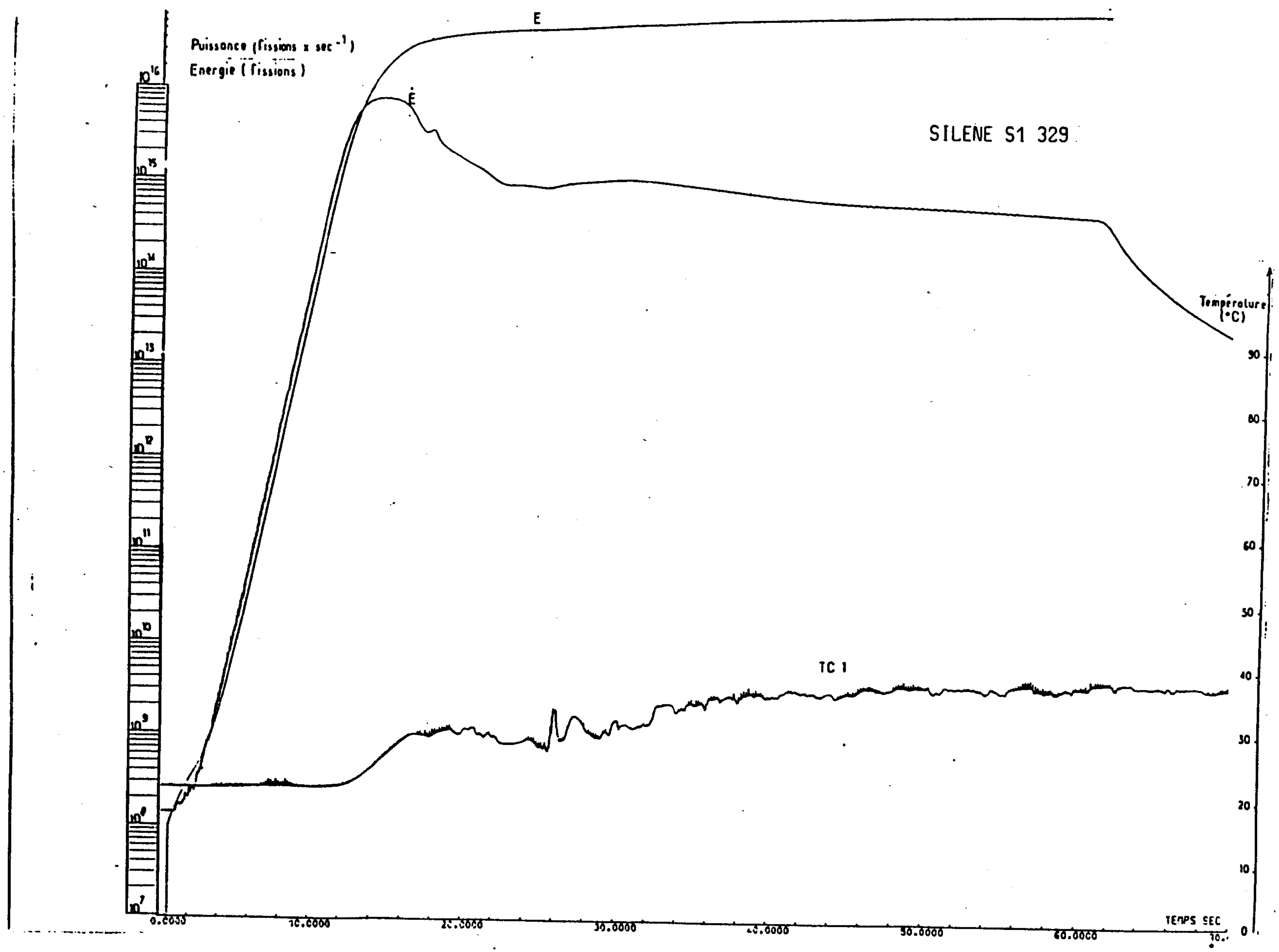
- SILENE 71 g/l configuration sans écran.
Débits de dose neutrons et gamma à 4 m de l'axe du réacteur.



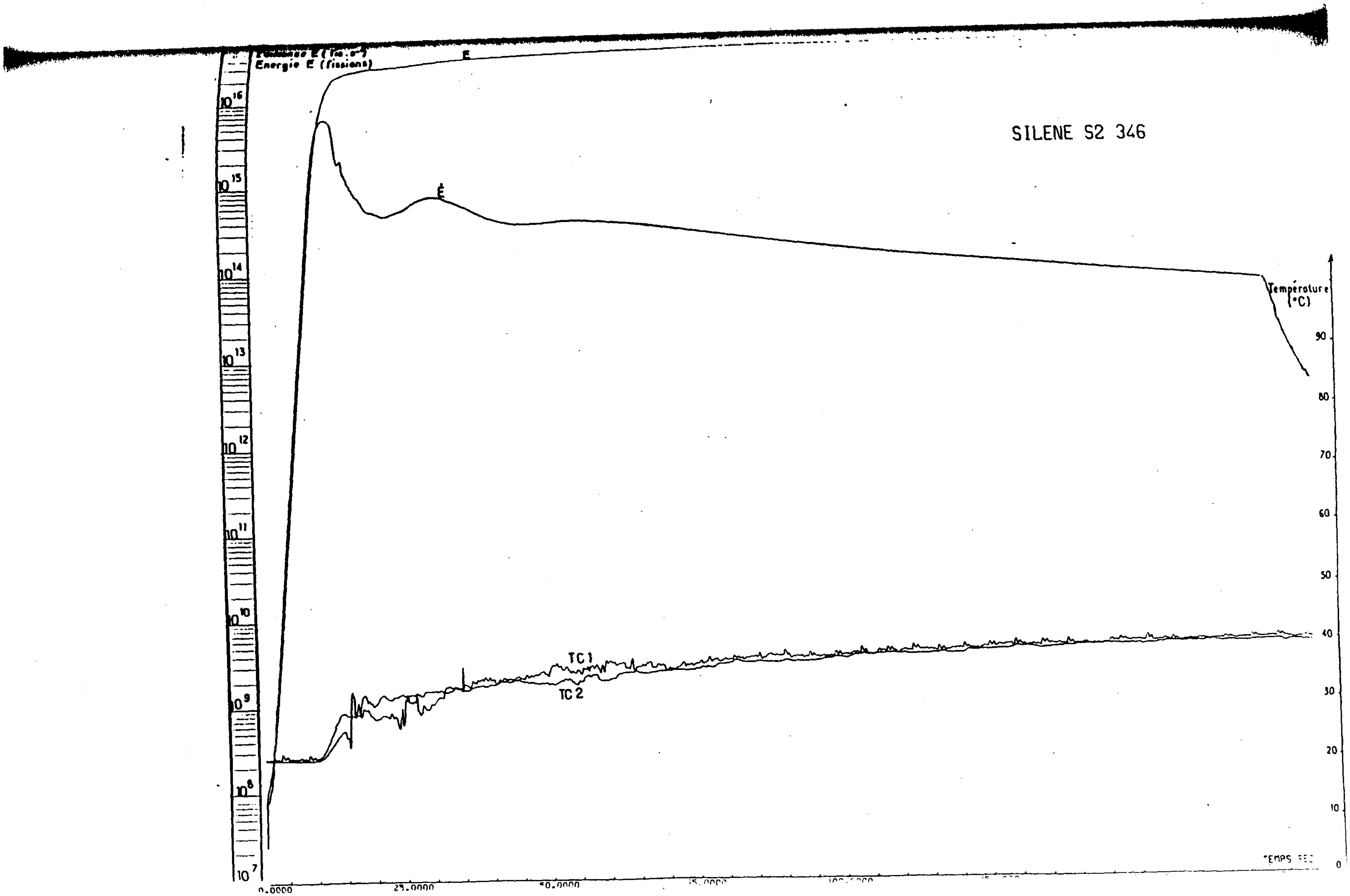
Puissance, énergie et température



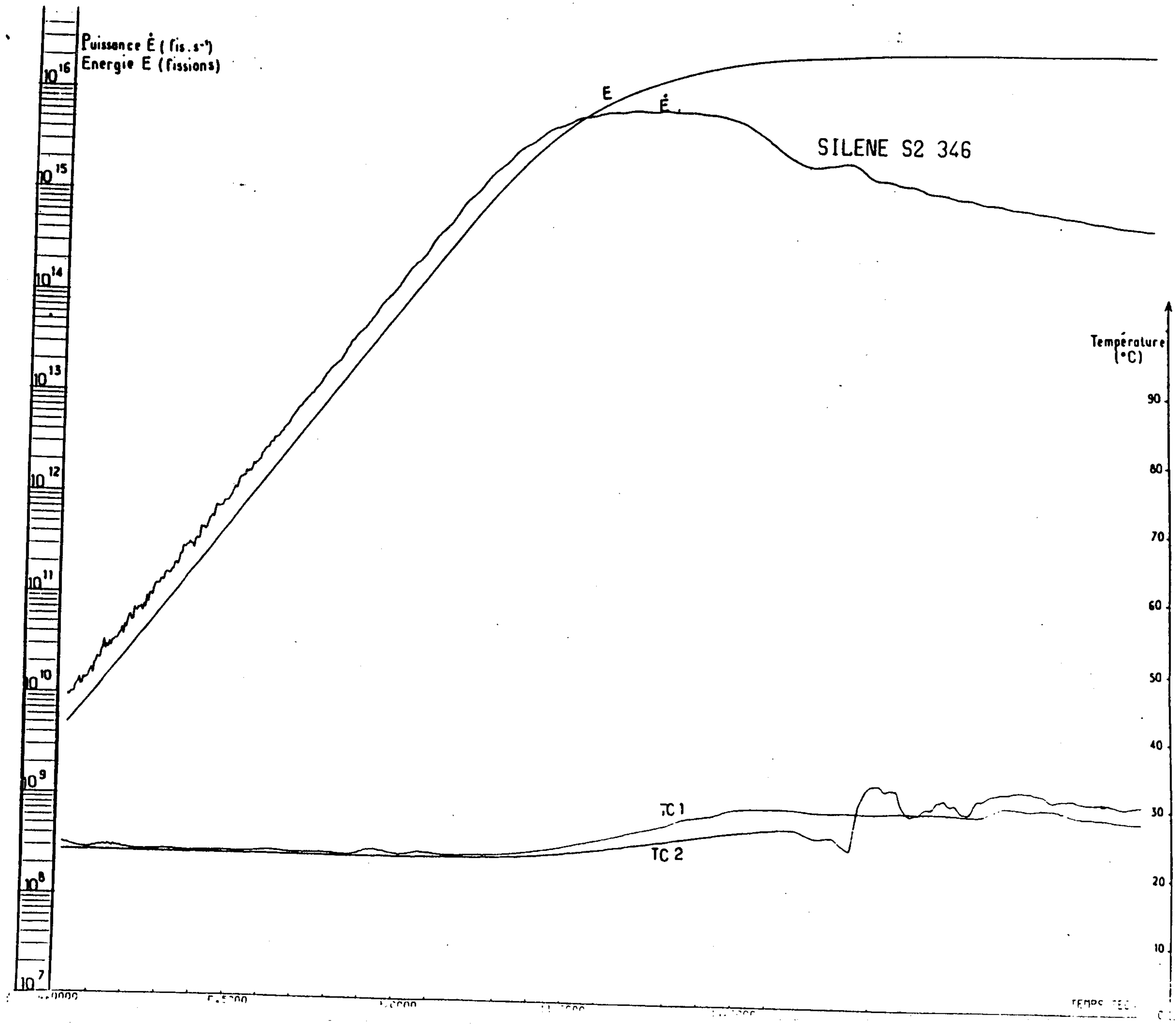
Puissance, énergie et température (détail 1er pic)



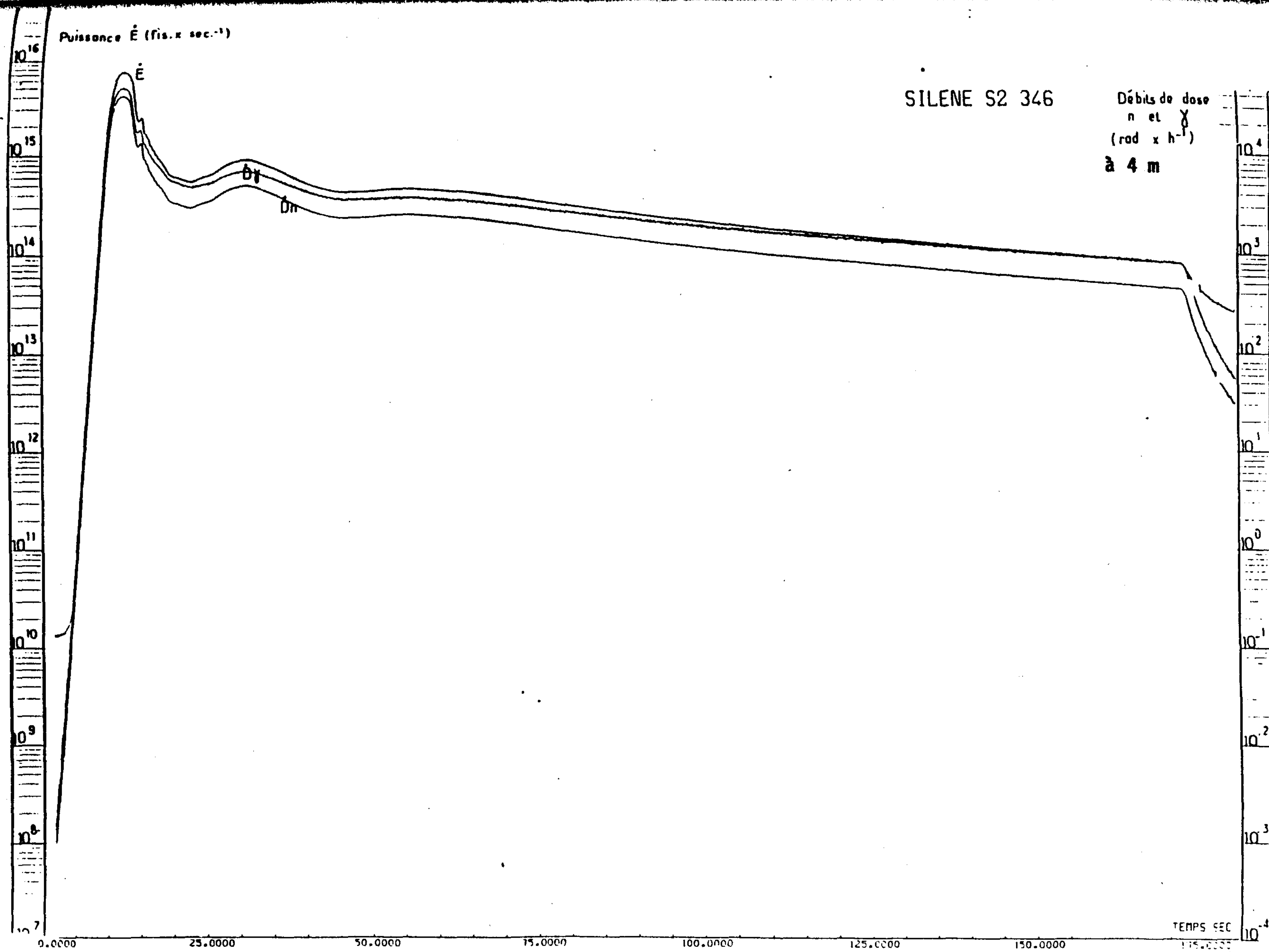
Puissance (fissions x sec⁻¹)
Energie (fissions)
SILENE S1 329
E
Ė
TC 1
Température (°C)
TEMPS SEC



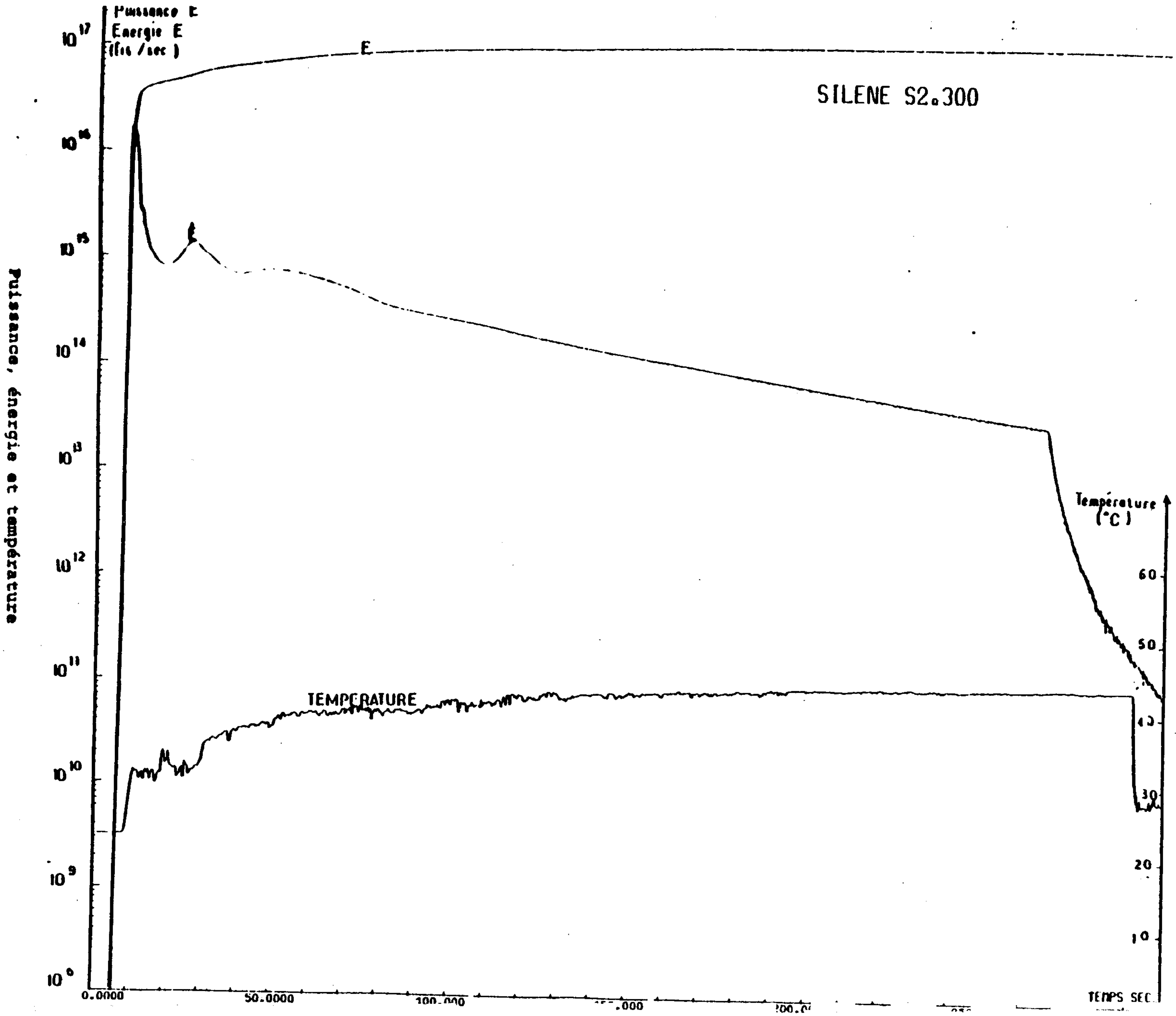
Energie E (fissions)
E
Ė
SILENE S2 346
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
Température (°C)
90
80
70
60
50
40
30
20
10
0
TC 1
TC 2
0.0000
25.0000
50.0000



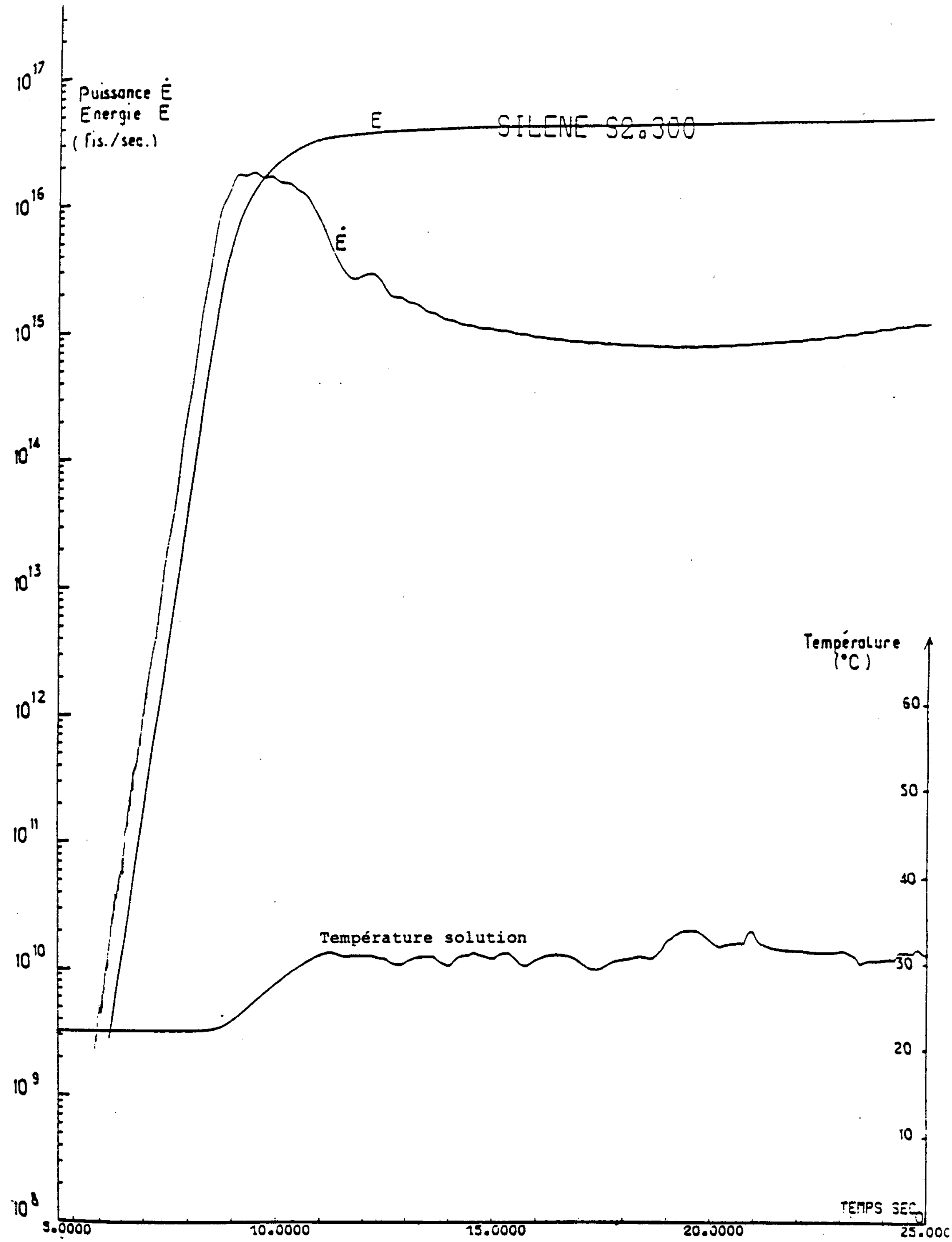
Puissance Ė (fis.s⁻¹)
Energie E (fissions)
E
Ė
SILENE S2 346
Température (°C)
TC 1
TC 2



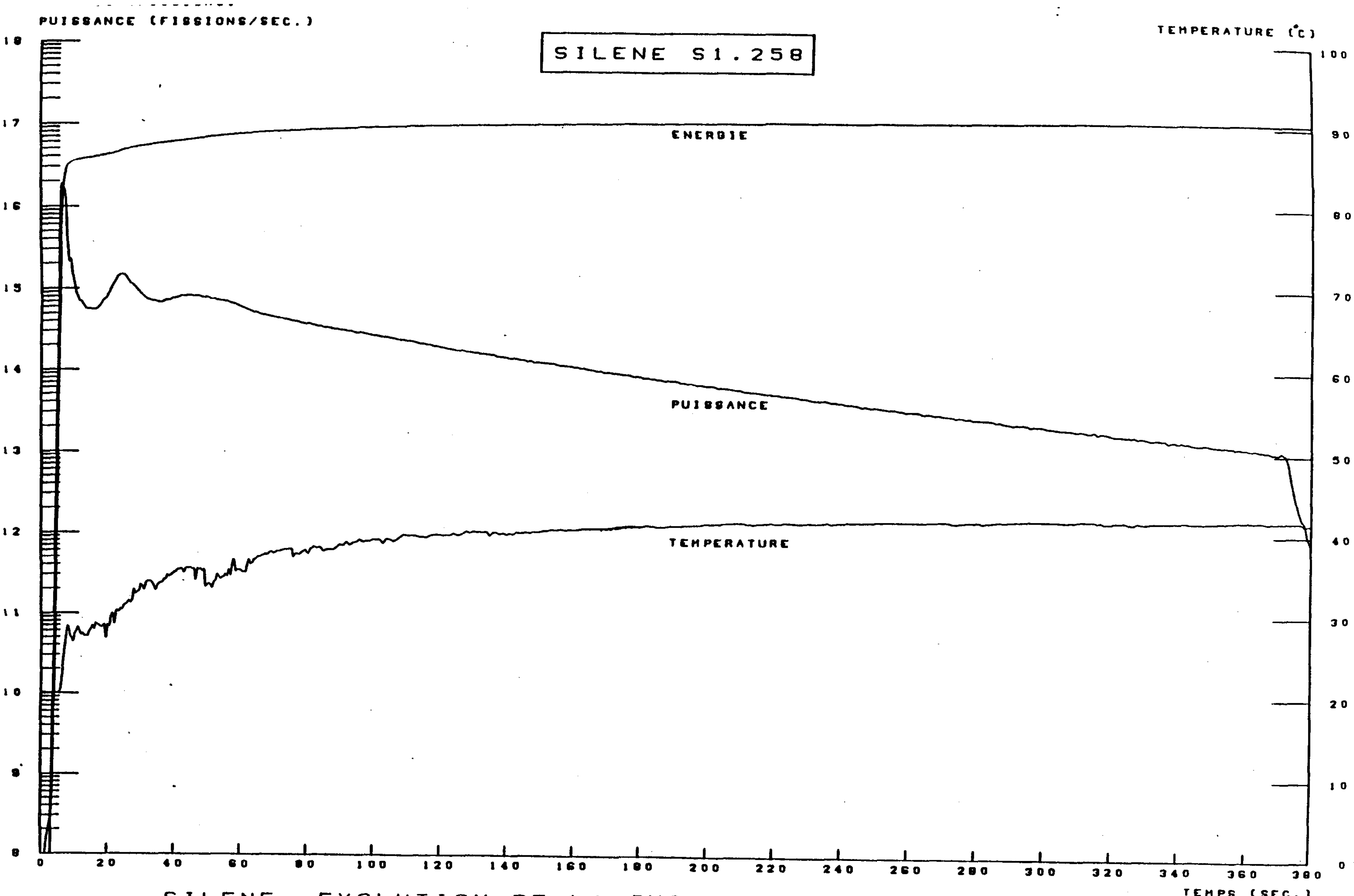
Puissance Ė (fis.x sec.⁻¹)
Ė
SILENE S2 346
Débits de dose
n et γ
(rad x h⁻¹)
à 4 m
Ḋγ
Ḋn
TEMPS SEC
0.0000
25.0000
50.0000
75.0000
100.0000
125.0000
150.0000



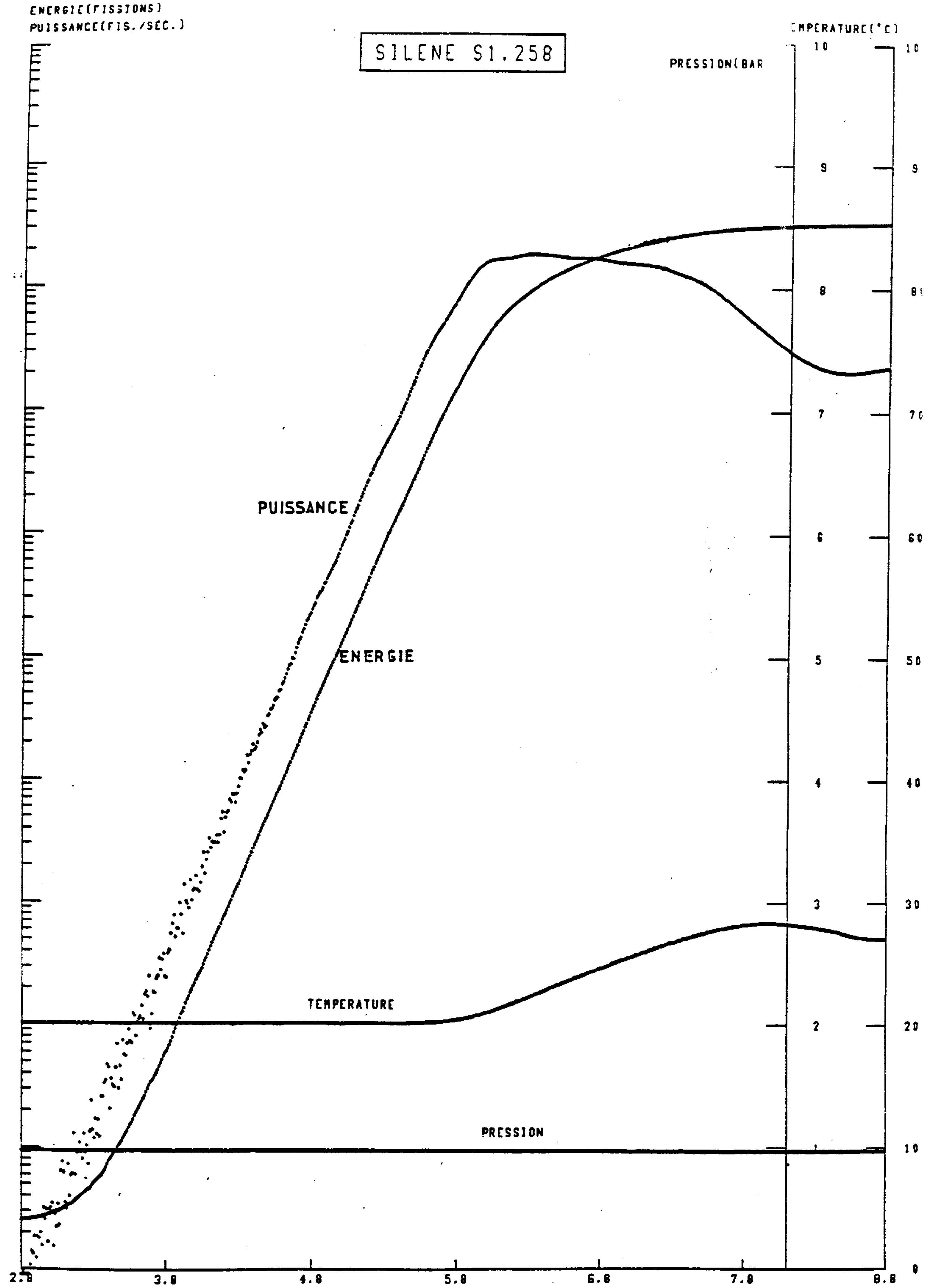
Puissance E
Energie E
(fis/sec)
E
SILENE S2.300
TEMPERATURE
Température (°C)
60
50
20
10
TEMPS SEC.
0.0000
50.0000
Puissance, énergie et température



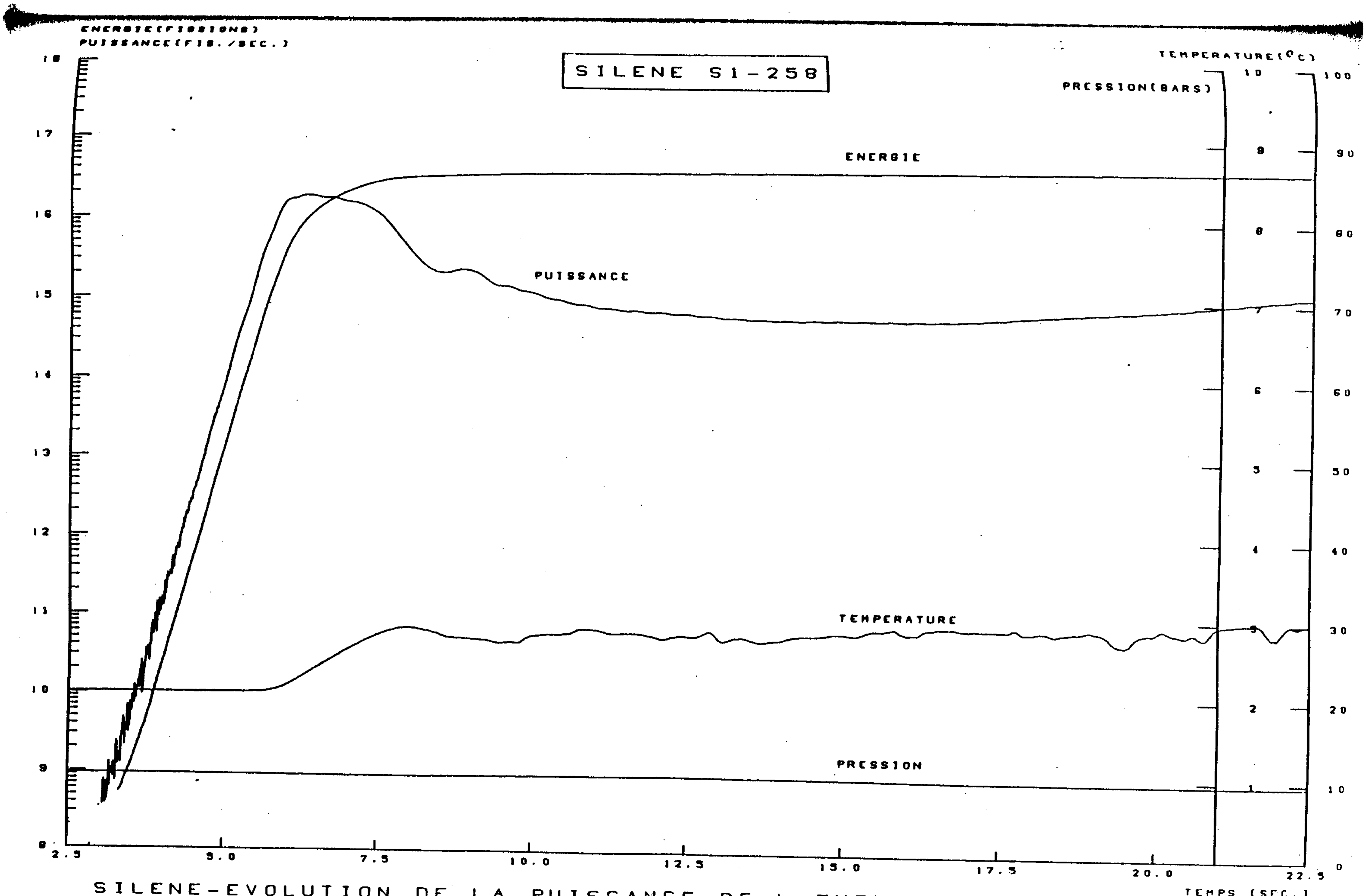
Puissance, énergie et température



SILENE EVOLUTION DE LA PUISSANCE, DE L'ENERGIE ET DE
LA [illegible]



SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE, DE LA TEMPERATURE
ET DE LA PRESSION AU SEIN DU REACTEUR(1ER PIC DETAIL)

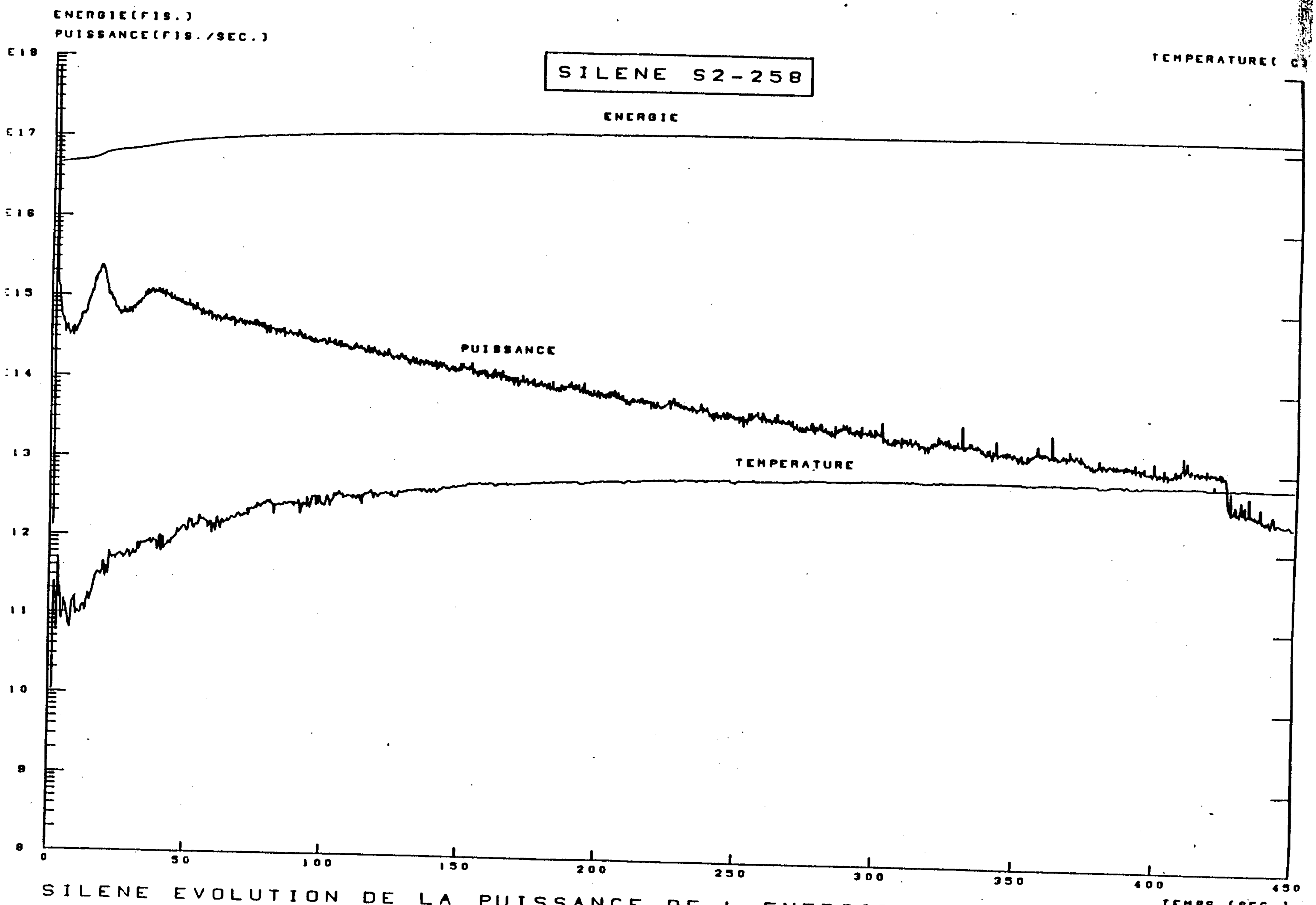


SILENE-EVOLUTION DE LA PUISSANCE DE L ENERGIE DE LA TEMPERAT...

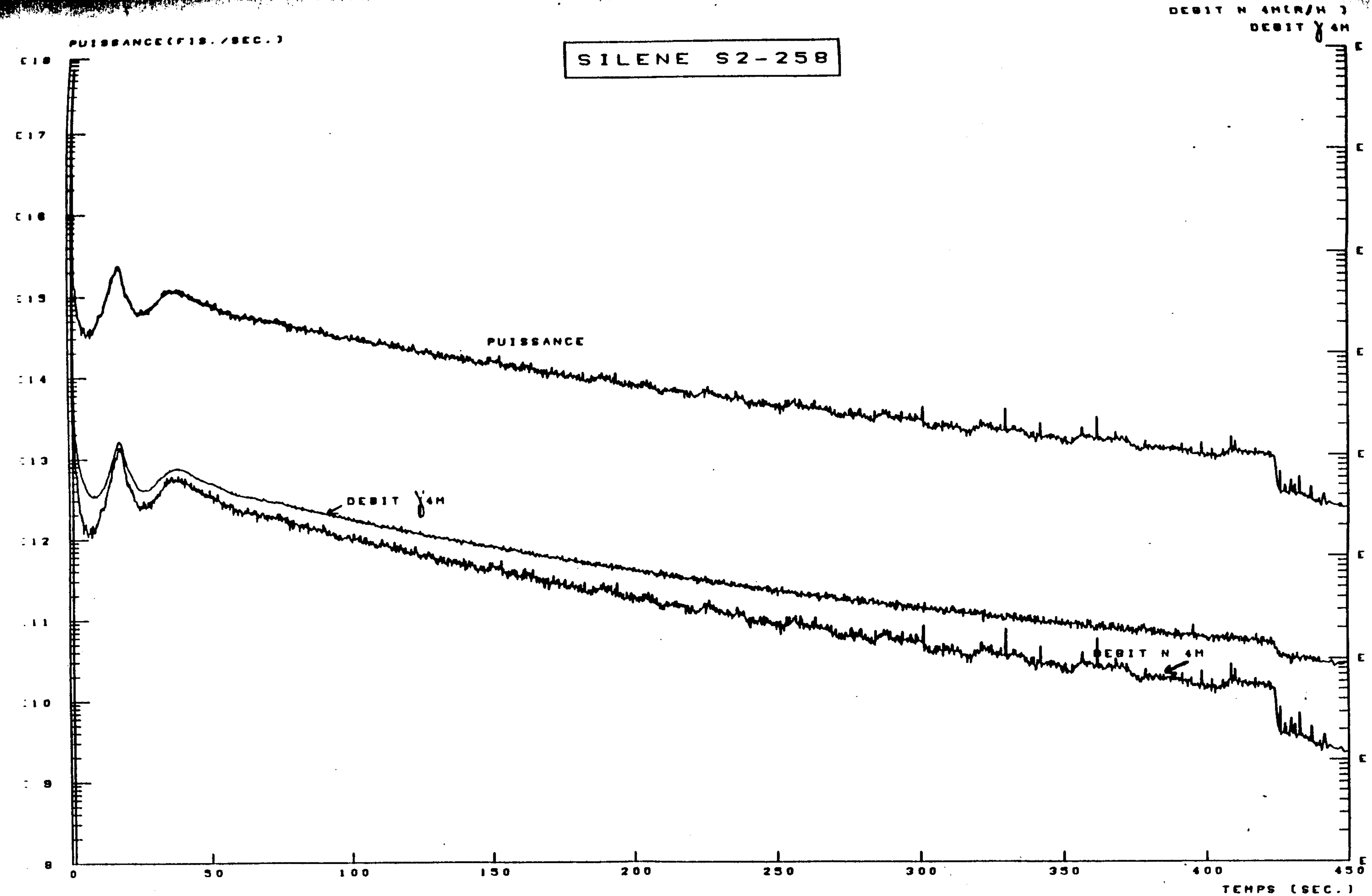
"PULSE" OPERATION EXPERIMENTS $\Delta k >> \beta$

NUMBER	$C_{U\,g/l}$	$H_{c\,cm}$	ΔH_{mm}	$H_{f\,cm}$	$V_{f\,l}$	1ST PEAK									
						$T_{2\,s}$	$\omega_{s^{-1}}$	t_s	$\dot{E}_{fissions\ s^{-1}}$	$\hat{E}_{fissions}$	E_{P_1}	E_{P_2}	ΔP_{bar}	$\Delta k_{1\,PCM}$	$\Delta k_{1\,S}$
S2-258	70.5	37.74	21.0	39.84	38.6	0.010	68.6	1.526	$7.1\ 10^{17}$	$1.8\ 10^{16}$	$4.5\ 10^{16}$	$4.7\ 10^{16}$		1046	1.32
S3-258	70.5	37.74	28.1	40.55	39.3	0.0038	181	1.432	$4.9\ 10^{18}$	$5.4\ 10^{16}$	$8.1\ 10^{16}$	$8.4\ 10^{16}$	1	1458	1.84
S1-362	69.9	37.57	46.0	42.17	40.9	0.00391	177	3.405	$5.3\ 10^{18}$	$5.6\ 10^{16}$	$8.5\ 10^{16}$	$8.5\ 10^{16}$	1.05	1420	1.79
S4-258	70.5	37.74	32.0	40.94	39.7	0.0028	249	1.798	$9.1\ 10^{18}$	$7.0\ 10^{16}$	$1.0\ 10^{17}$	$1.0\ 10^{17}$	1.9	1696	2.14
S3-300	70.8	37.36	36.0	40.96	39.7	0.00243	285	1.314	$1.1\ 10^{19}$	$6.6\ 10^{17}$	$1.0\ 10^{17}$	$1.0\ 10^{17}$	2.55	1832	2.31
S2-259	70.5	37.38	40.0	41.38	40.1	0.00198	350	1.238	$1.7\ 10^{19}$	$8.2\ 10^{16}$	$1.3\ 10^{17}$	$1.3\ 10^{17}$	3.7	2068	2.6
S4-259	70.5	37.38	44.0	41.78	40.5	0.00192	361	1.193	$1.8\ 10^{19}$	$8.6\ 10^{16}$	$1.3\ 10^{17}$	$1.3\ 10^{17}$	4.4	2108	2.65
S3-259	70.5	37.38	44.0	41.78	40.5	0.00171	405	1.365	$2.1\ 10^{19}$	$7.9\ 10^{16}$	$1.4\ 10^{17}$	$1.4\ 10^{17}$	4.8	2269	2.86
S4-346	70.9	36.81	46.0	41.41	40.2	0.00162	428	1.234	$2.4\ 10^{19}$	$9.8\ 10^{16}$	$1.5\ 10^{17}$	$1.5\ 10^{17}$	5.6	2350	2.96
S1-346	70.9	36.82	46.0	41.42	40.2	0.00162	428	1.170	$2.5\ 10^{19}$	$9.8\ 10^{16}$	$1.5\ 10^{17}$	$1.5\ 10^{17}$	5.6	2350	2.96

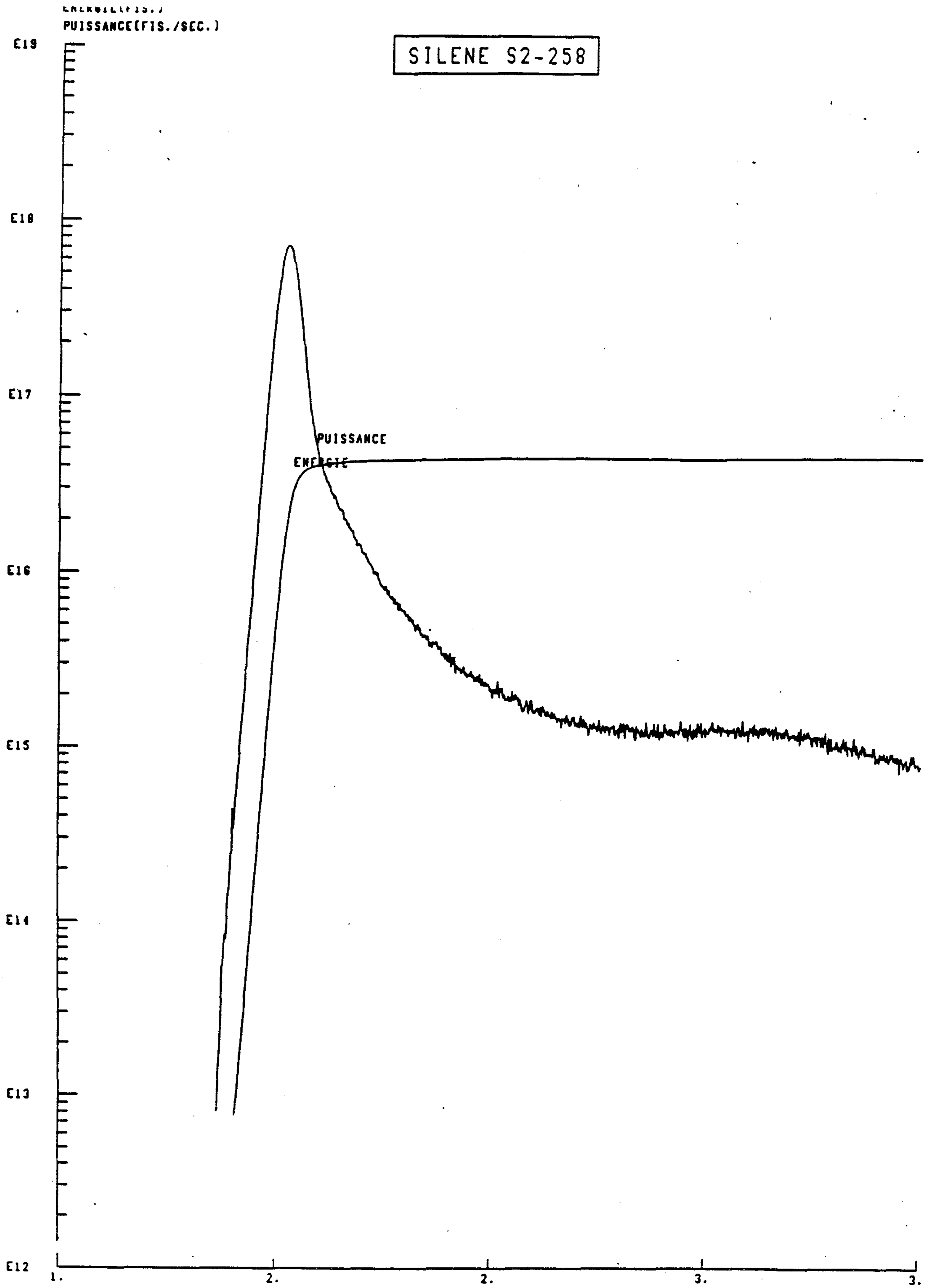
NUMBER	$t_{eq\,s}$	$E_{eq\,fissions}$	TEMPERATURE		TOTAL REACTIVITY ADDITION		DURATION	$N_{f\,fissions}$	SOURCE	OBJECTIVES	CATEGORY
			$\Theta_{i\,°C}$	$\Delta\Theta_{°C\,max}$	$\Delta k_{p\,pcm}$	$\Delta k_{p\,S}$					
S2-258	50	$8.8\ 10^{16}$	20.4	28.3	1046	1.32	11220	$1.5\ 10^{17}$	non	Cinétique +rentrée de la barre à t = 7 min	3
S3-258	90	$1.42\ 10^{17}$	20.4	35.7	1458	1.84	420	$1.9\ 10^{17}$	non	Cinétique	3
S1-362	160	$2.6\ 10^{17}$	20	50	2350	2.96	210	$2.8\ 10^{17}$	oui	Salve avec source éjection barre Cd : 20 cm.s^{-1}	4.7
S4-258	90	$1.7\ 10^{17}$	20.5	40.2	1696	2.14	420	$2.3\ 10^{17}$	non	Cinétique	3
S3-300	80	$1.8\ 10^{17}$	22.3	39.9	1832	2.31	120	$2.1\ 10^{17}$	non	Cinétique	3
S2-259	90	$2.1\ 10^{17}$	20.6	47.4	2068	2.6	420	$2.7\ 10^{17}$	non	Cinétique	3
S4-259	90	$2.2\ 10^{17}$	20.8	50.9	2108	2.65	10920	$2.9\ 10^{17}$	oui	Cinétique + rentrée de la barre à t = 7 min	4
S3-259	70	$2.1\ 10^{17}$	20.7	51.1	2269	2.86	420	$2.9\ 10^{17}$	non	Cinétique	3
S4-346	180	$2.9\ 10^{17}$	21.5	53	2350	2.96	180	$2.9\ 10^{17}$	non	Ejection barre Cd rapide 1.5 m.s^{-1}	3.7
S1-346	180	$2.9\ 10^{17}$	21	53	2350	2.96	180	$2.9\ 10^{17}$	oui	Ejection barre Cd rapide 1.5 m.s^{-1}	4.7



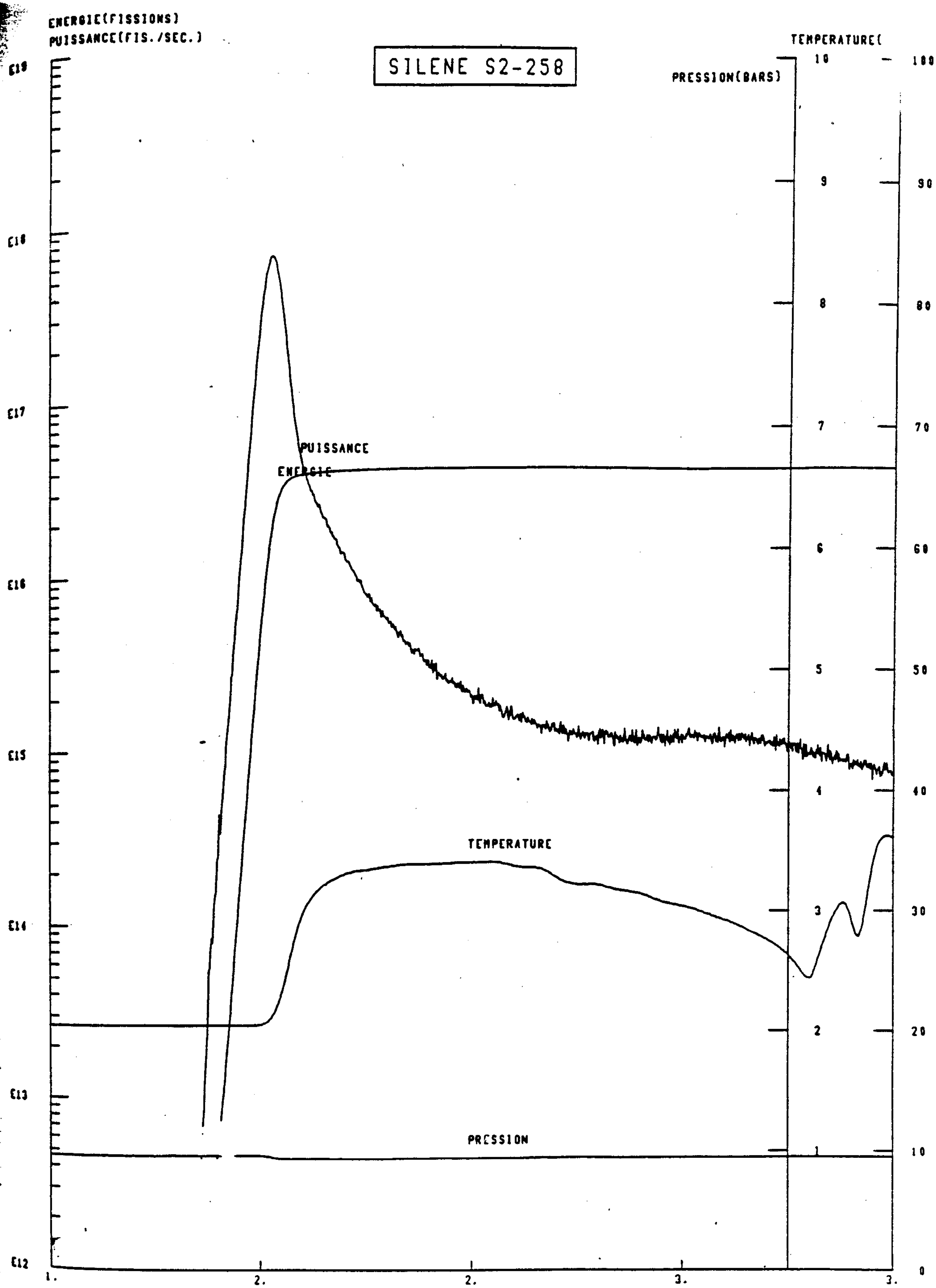
SILENE EVOLUTION DE LA PUISSANCE,DE L ENERGIE ET DE LA TEMPERATURE
AU SEIN DU REACTEUR



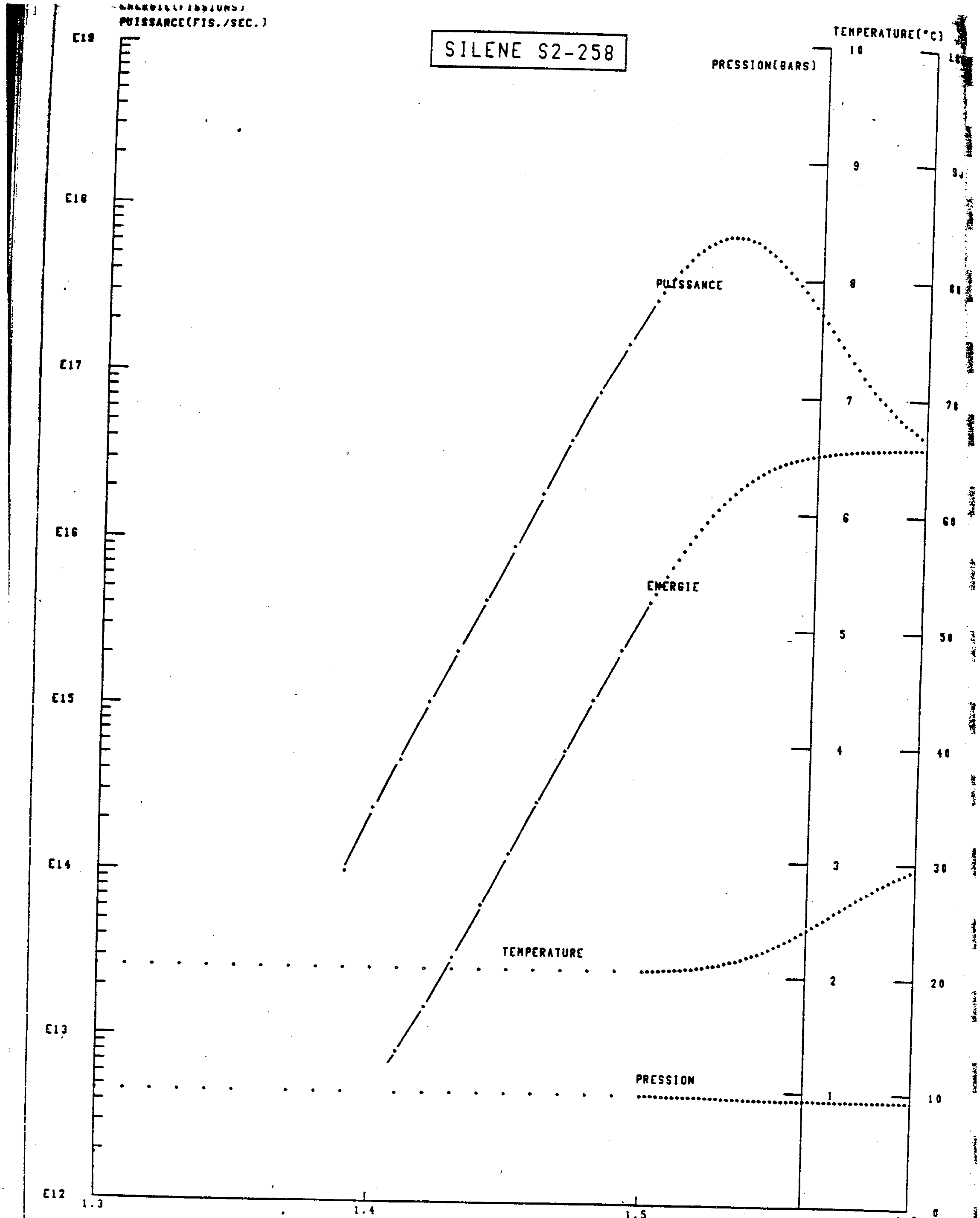
SILENE- EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR ET DEBITS DE DOSES N ET G A 4M



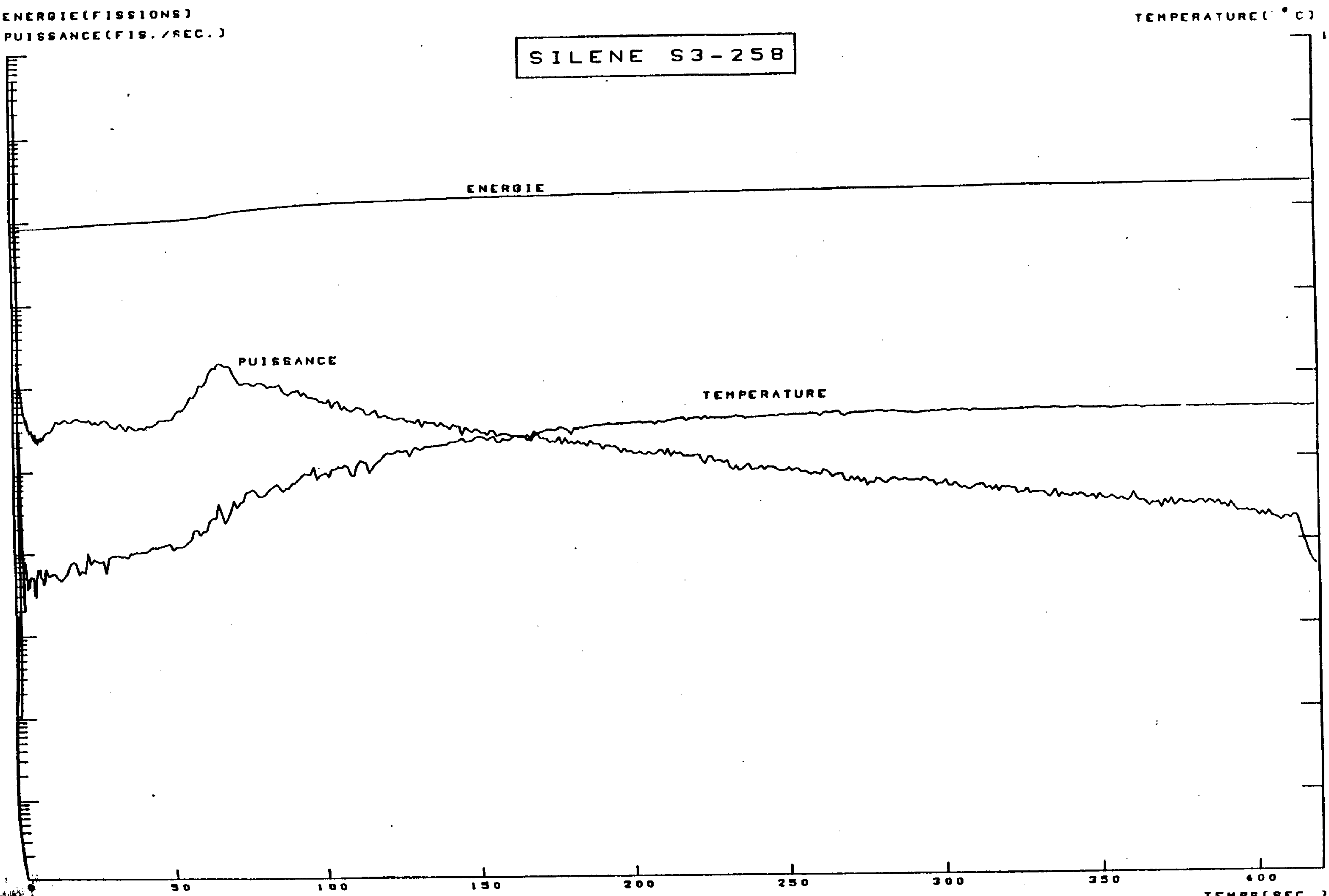
SILENE-EVOLUTION DE LA PUISSANCE ET DE L ENERGIE
AU SEIN DU REACTEUR (PREMIER PIC)



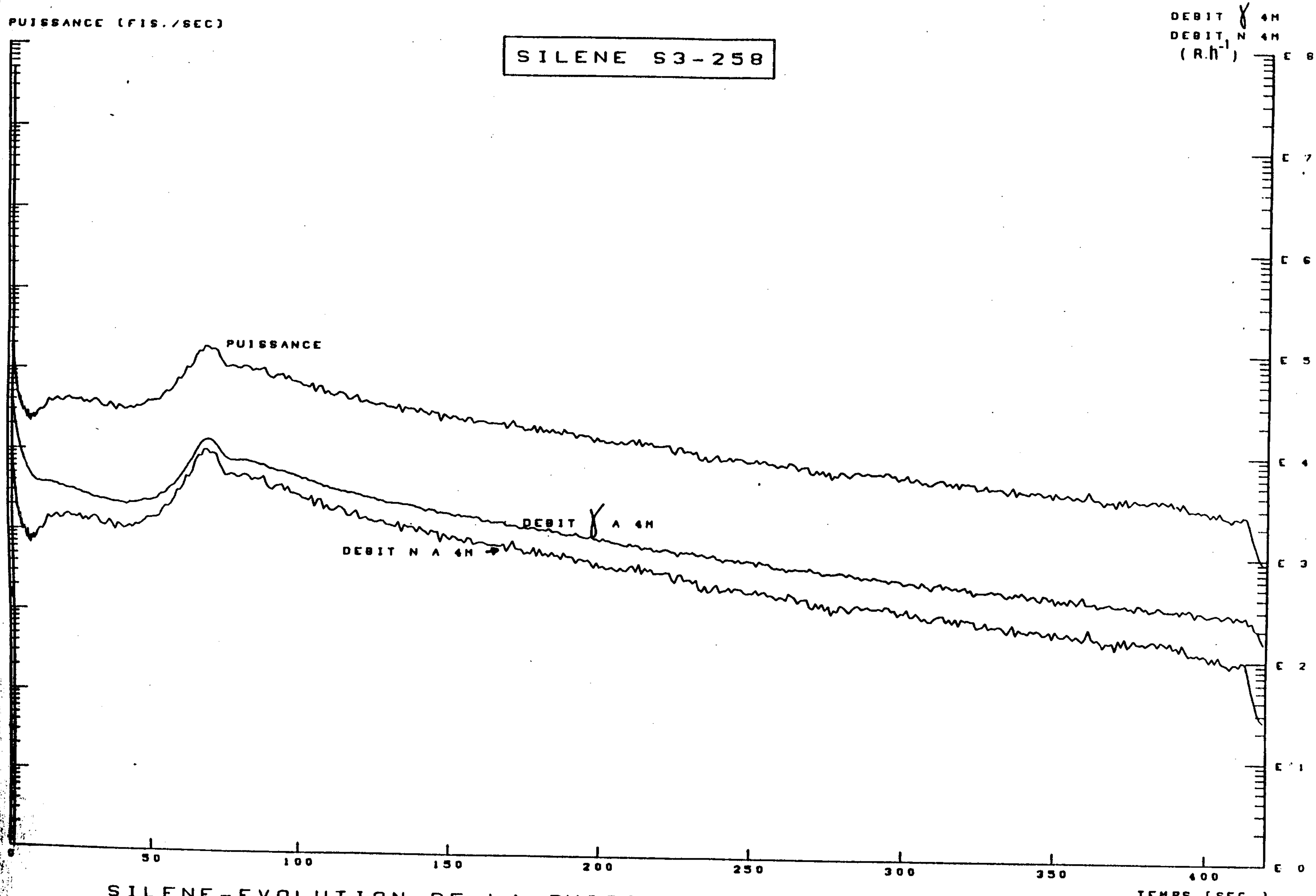
SILENE-EVOLUTION DE LA PUISSANCE.DE L ENERGIE.DE



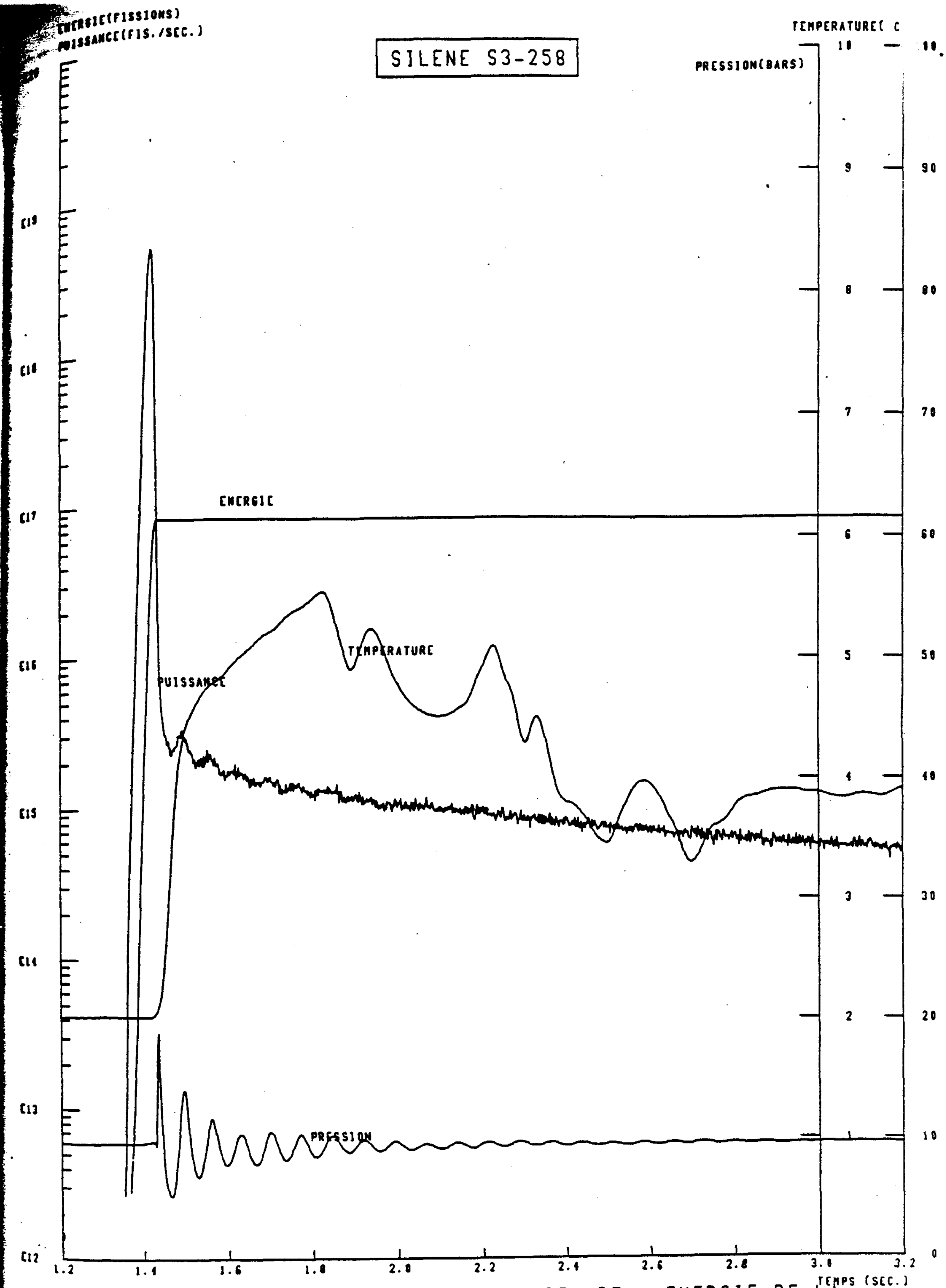
SILENE EVOLUTION DE LA PUISSANCE, DE L'ENERGIE
DE LA TEMPERATURE ET DE LA PRESSION(PREMIER PIC DETAIL)



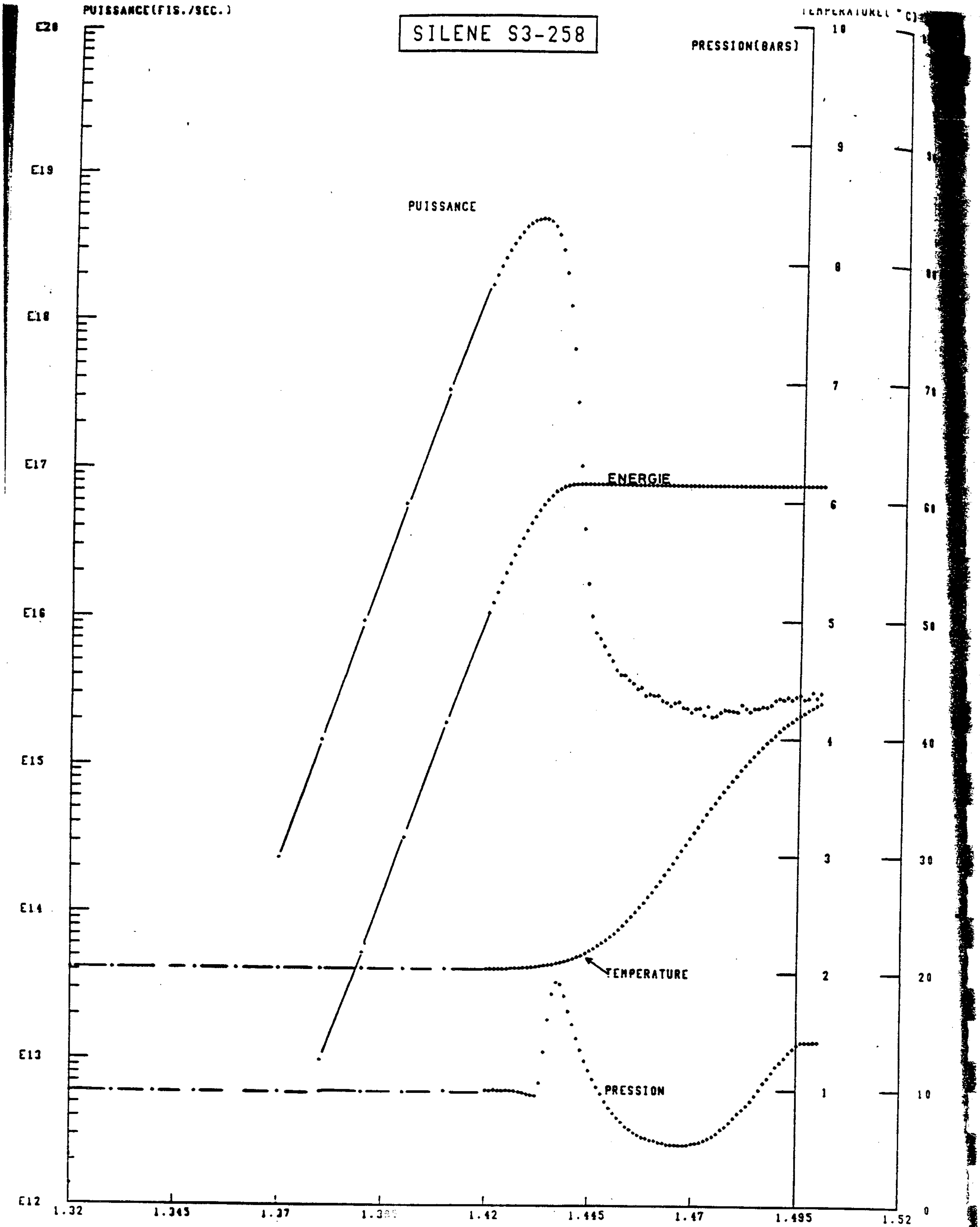
SILENE -EVOLUTION DE LA PUISSANCE DE L'ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



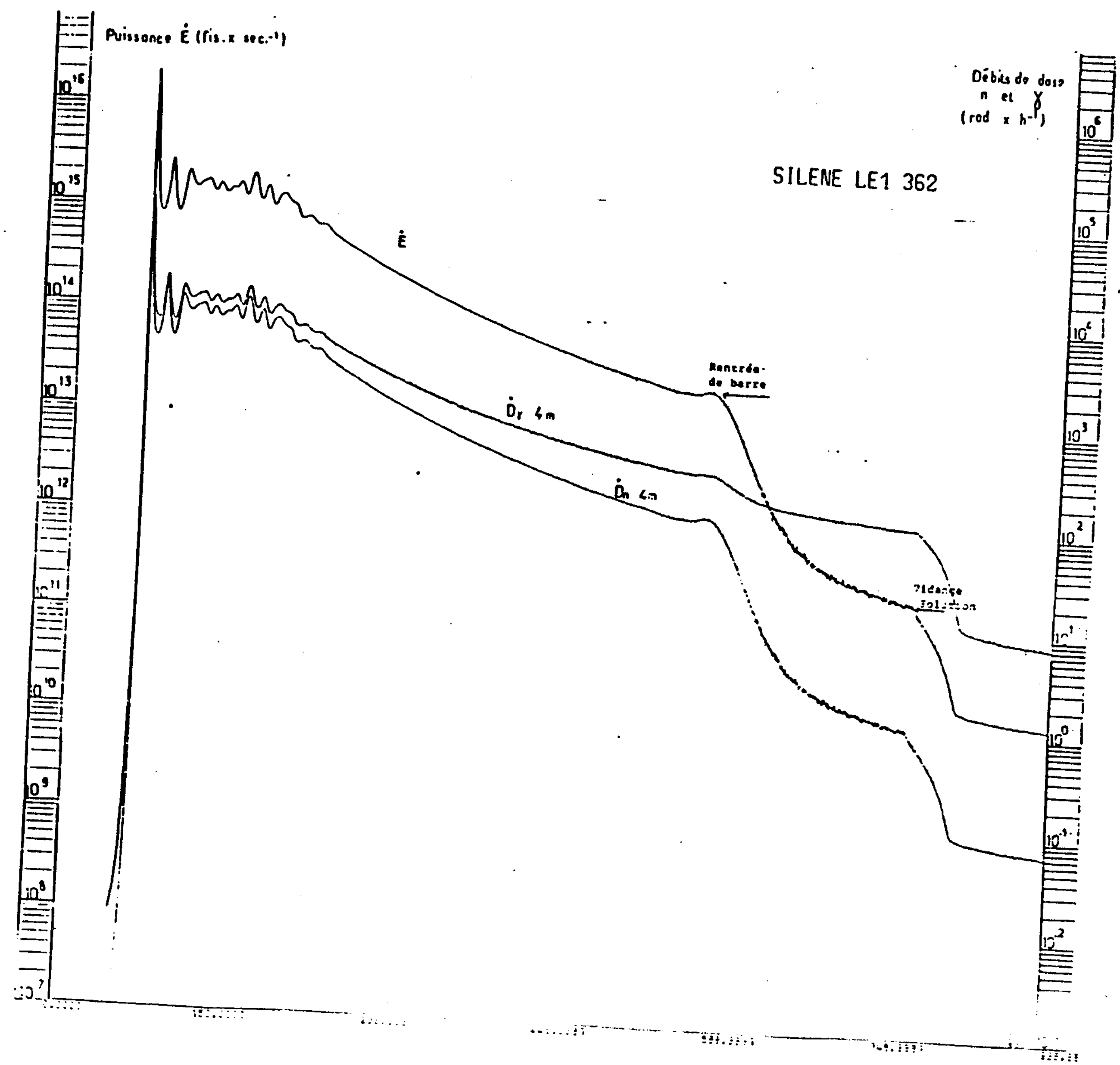
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR, ET DEBITS DE DOSES N ET γ A 4M DU REACTEUR.



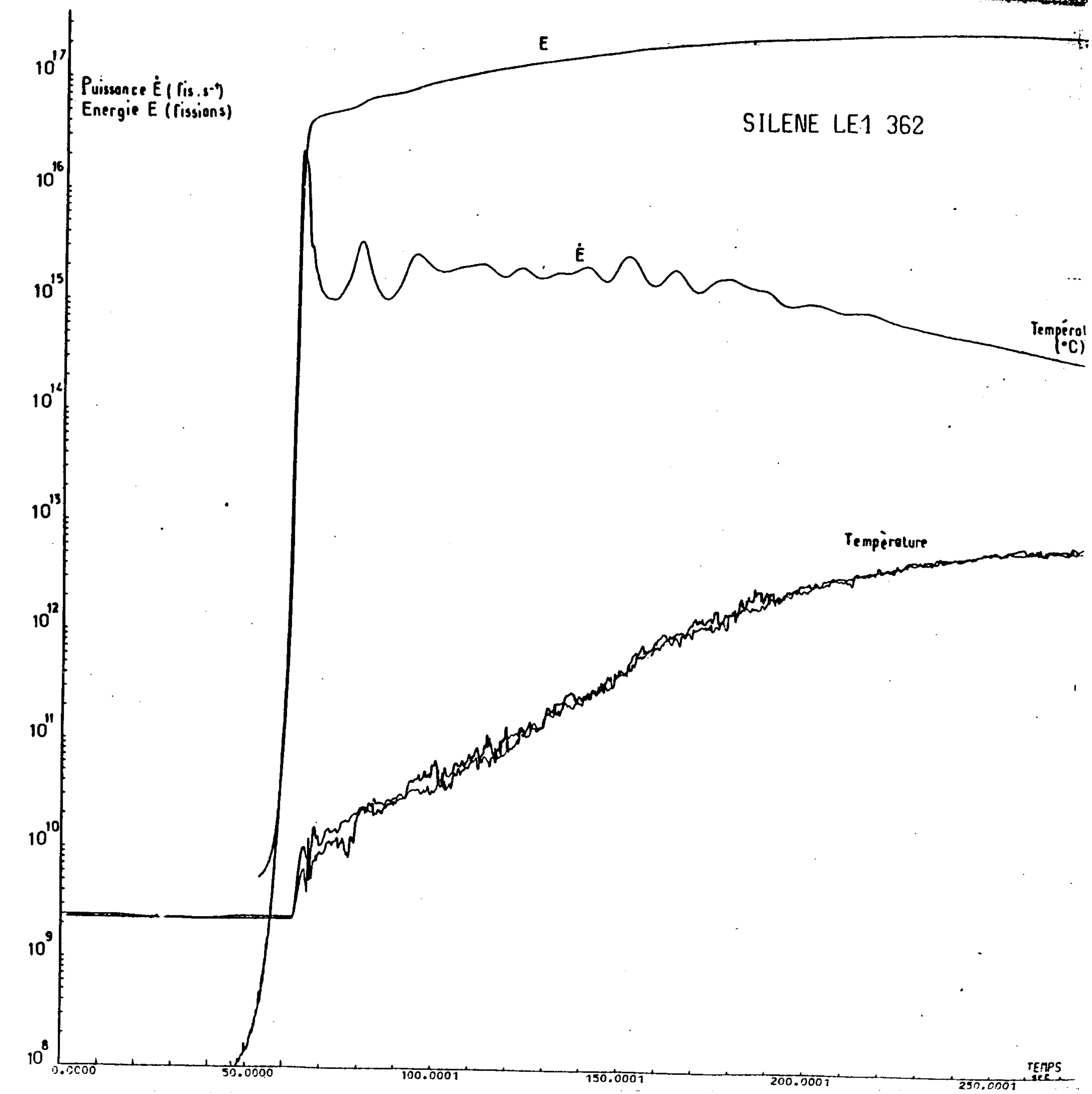
SILENE-EVOLUTION DE LA PUISSANCE ,DE L ENERGIE,DE LA TEMPERATURE ET DE LA PRESSION AU SEIN DU REACTEUR

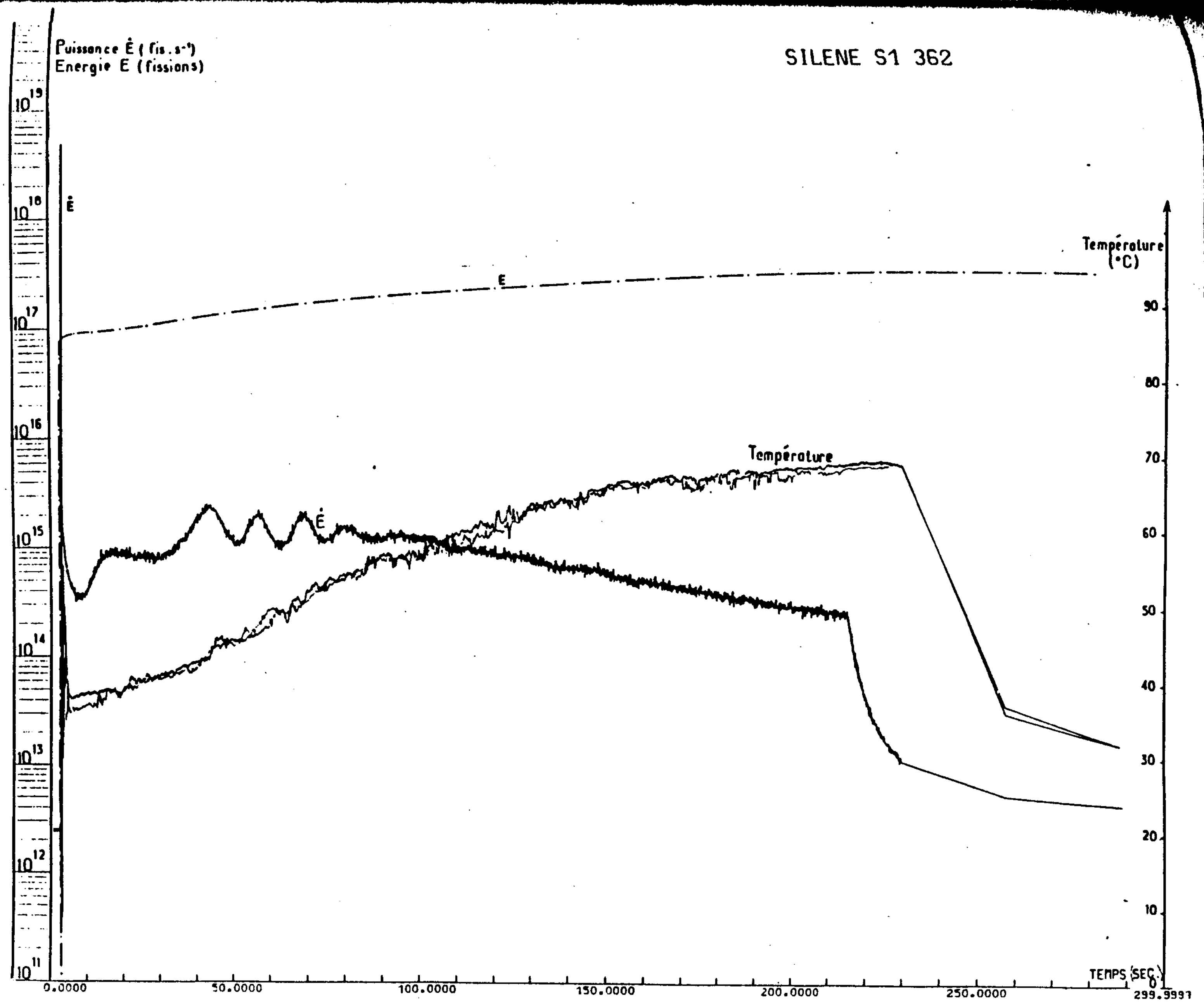


SILENE-EVOLUTION DE LA PUISSANCE DE L'ENERGIE

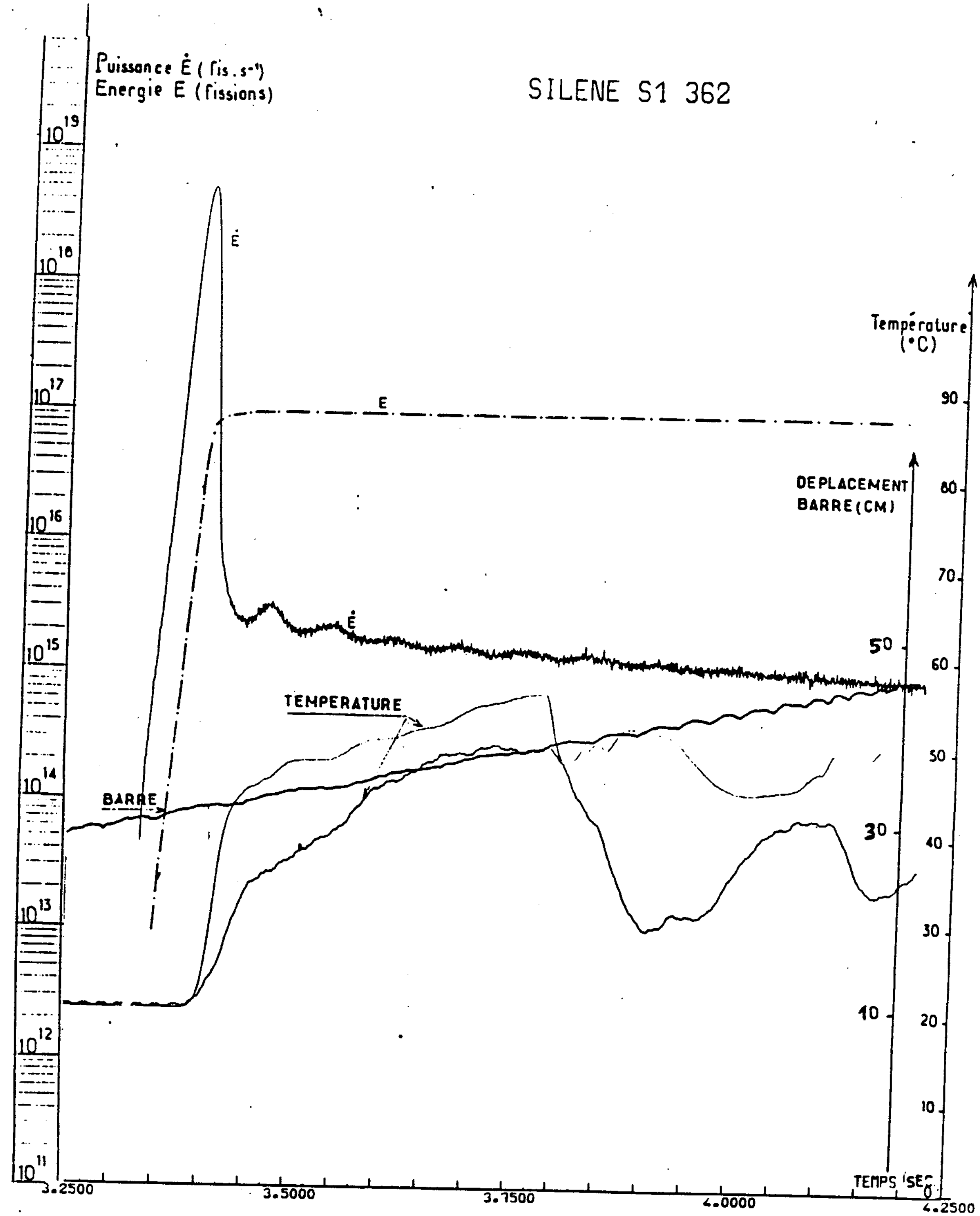


Puissance Ė (fis.x sec.⁻¹)
Débits de dose
n et γ
(rad x h⁻¹)
SILENE LE1 362
Ė
Rentrée de barre
Ḋγ 4m
Ḋn 4m
Vidange solution

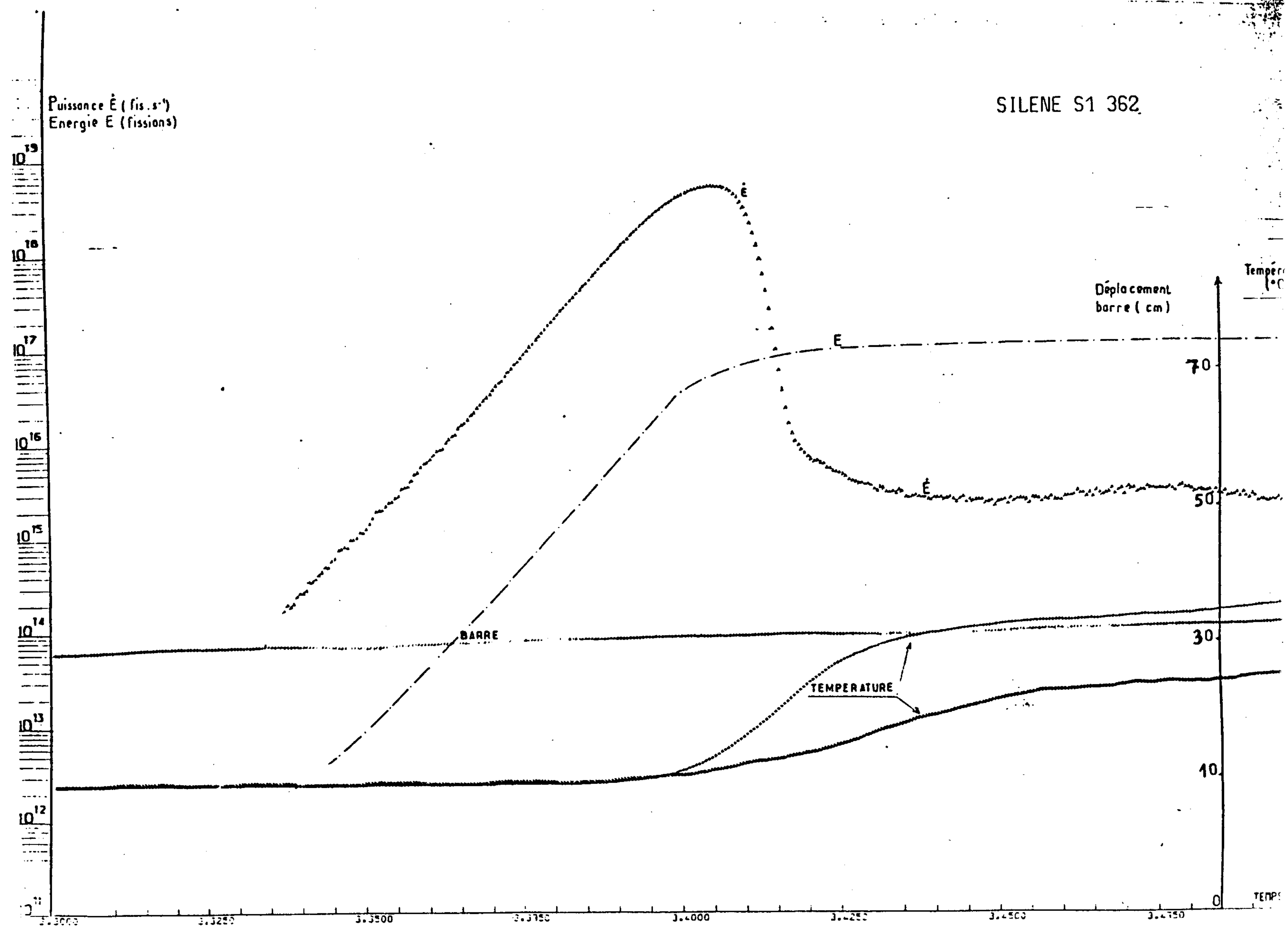

Puissance Ė (fis.s⁻¹)
Energie E (fissions)
SILENE LE1 362
E
Ė
Température
Températ (°C)
TEMPS sec
0.0000
50.0000
100.0001
150.0001
200.0001
250.0001
10^17
10^16
10^15
10^14
10^13
10^12
10^11
10^10
10^9
10^8

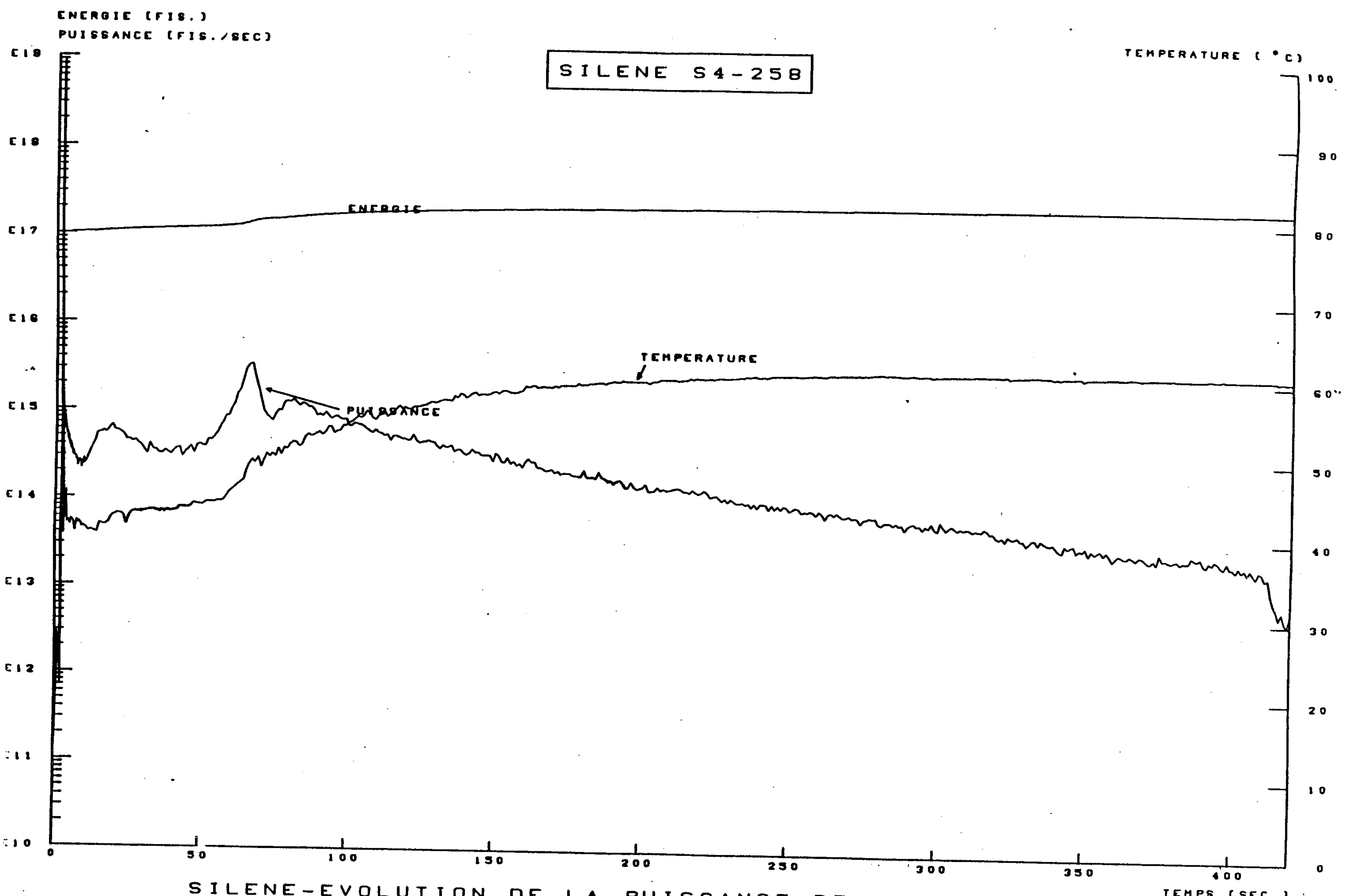


SILENE S1 362
Puissance Ė (fis.s⁻¹)
Energie E (fissions)
10¹⁹
10¹⁸
10¹⁷
10¹⁶
10¹⁵
10¹⁴
10¹³
10¹²
10¹¹
Ė
E
Température
Température (°C)
90
80
70
60
50
40
30
20
10
0
TEMPS (SEC.)
0.0000
50.0000
100.0000
150.0000
200.0000
250.0000
299.9997

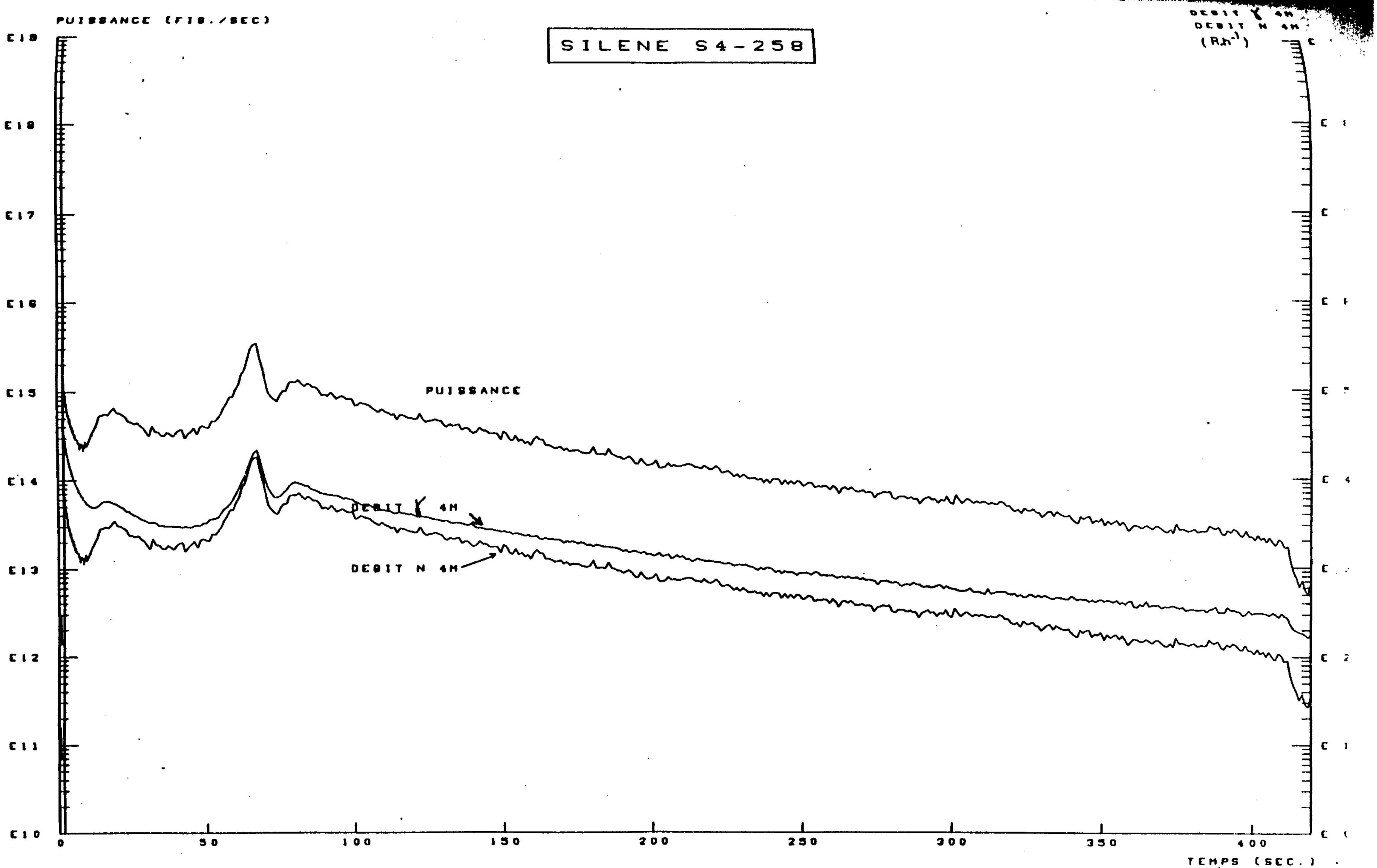

SILENE S1 362
Puissance Ė (fis.s⁻¹)
Energie E (fissions)
Température (°C)
DEPLACEMENT BARRE (CM)
Ė
E
TEMPERATURE
BARRE
TEMPS (SEC)
3.2500
3.5000
3.7500
4.0000
4.2500

SILENE S1 362

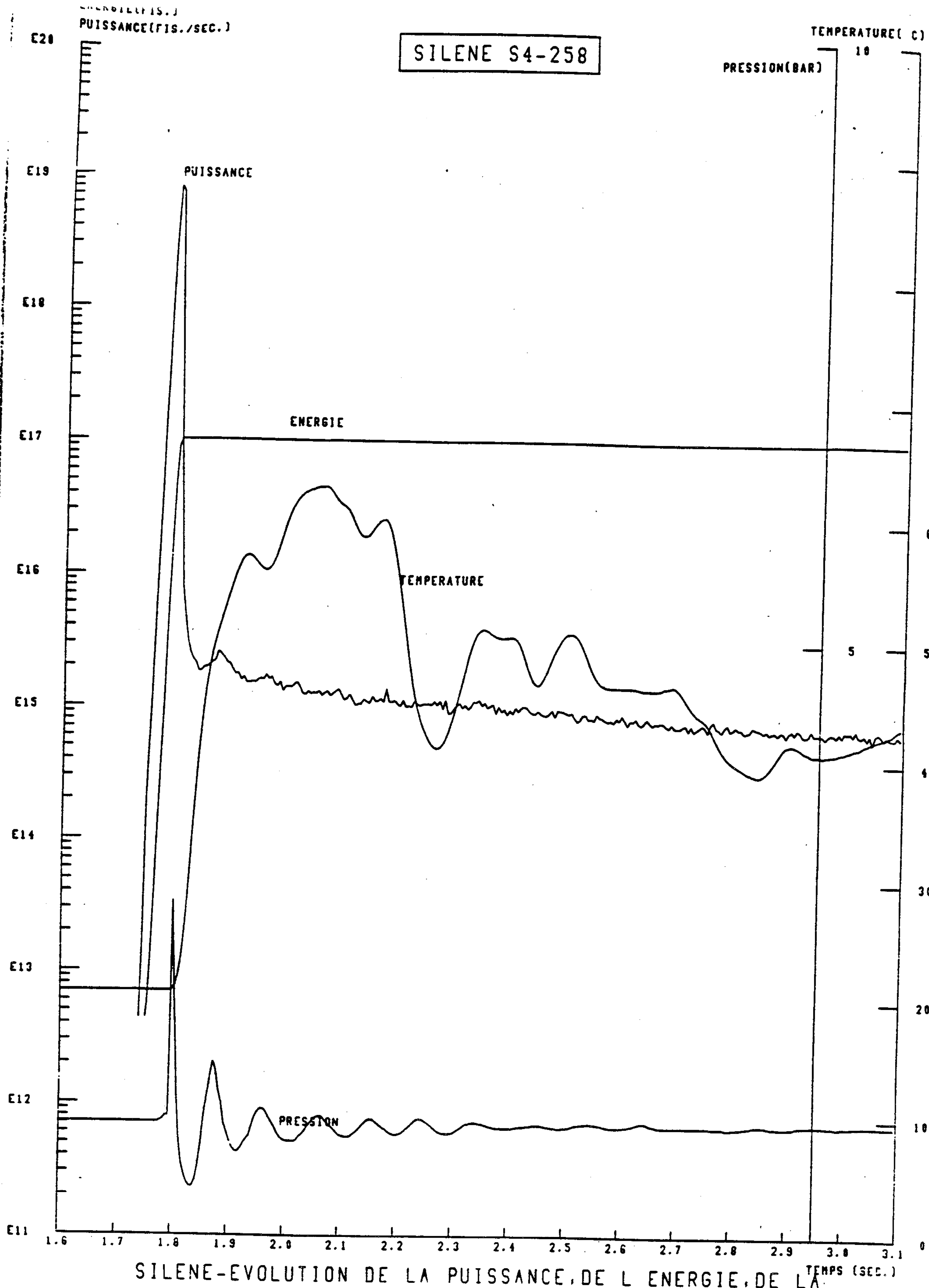




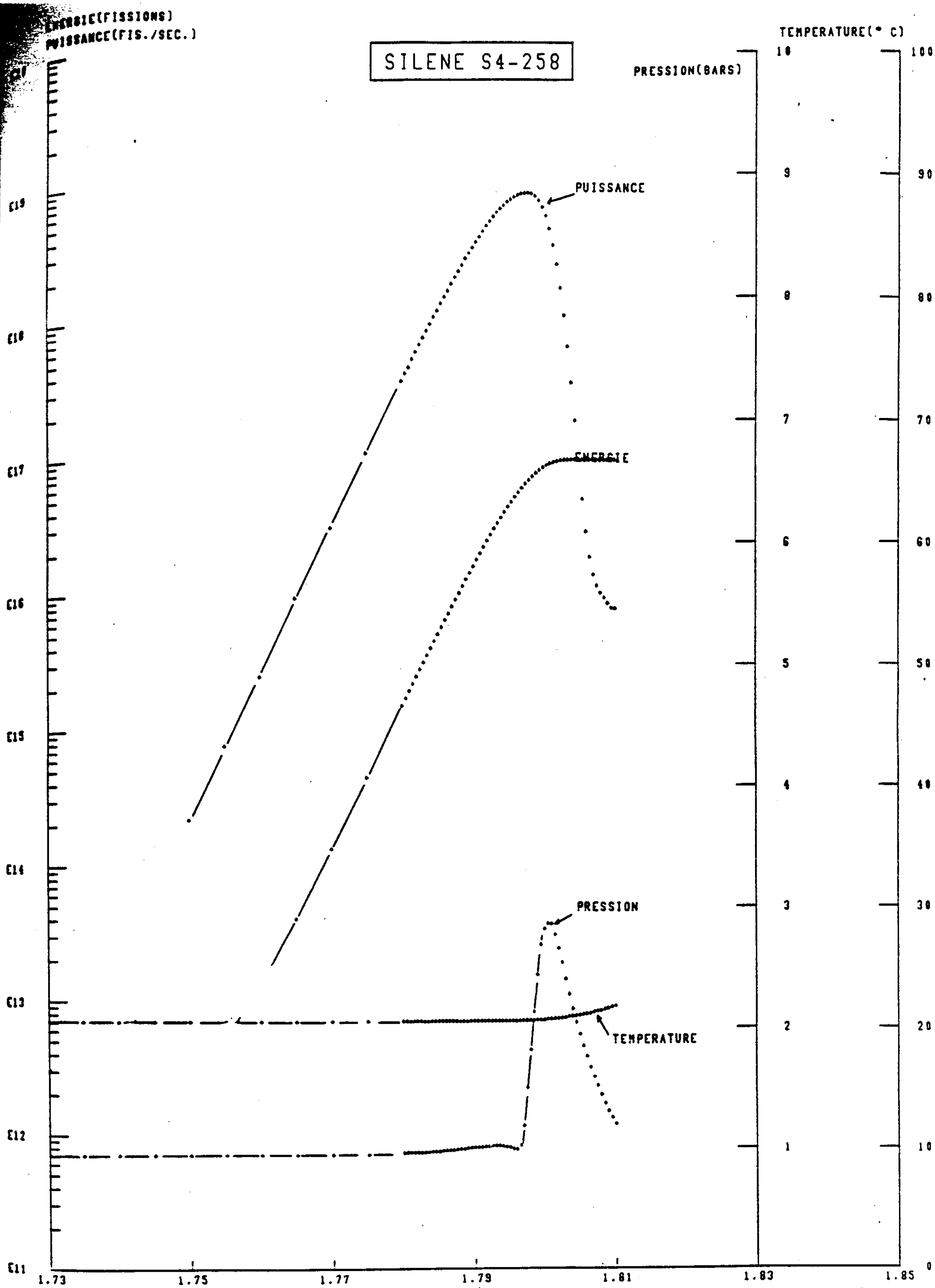
SILENE-EVOLUTION DE LA PUISSANCE, DE L'ENERGIE, DE LA TEMPERATURE AU SEIN DU REACTEUR.



SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR.
ET DEBITS DE DOSES N ET γ A 4M.



SILENE-EVOLUTION DE LA PUISSANCE,DE L ENERGIE,DE LA TEMPERATURE ET DE LA PRESSION AU SEIN DU REACTEUR(1ER PIC)



SILENE-EVOLUTION DE LA PUISSANCE, DE L'ENERGIE, DE LA TEMPERATURE ET DE LA PRESSION AU SEIN DU REACTEUR

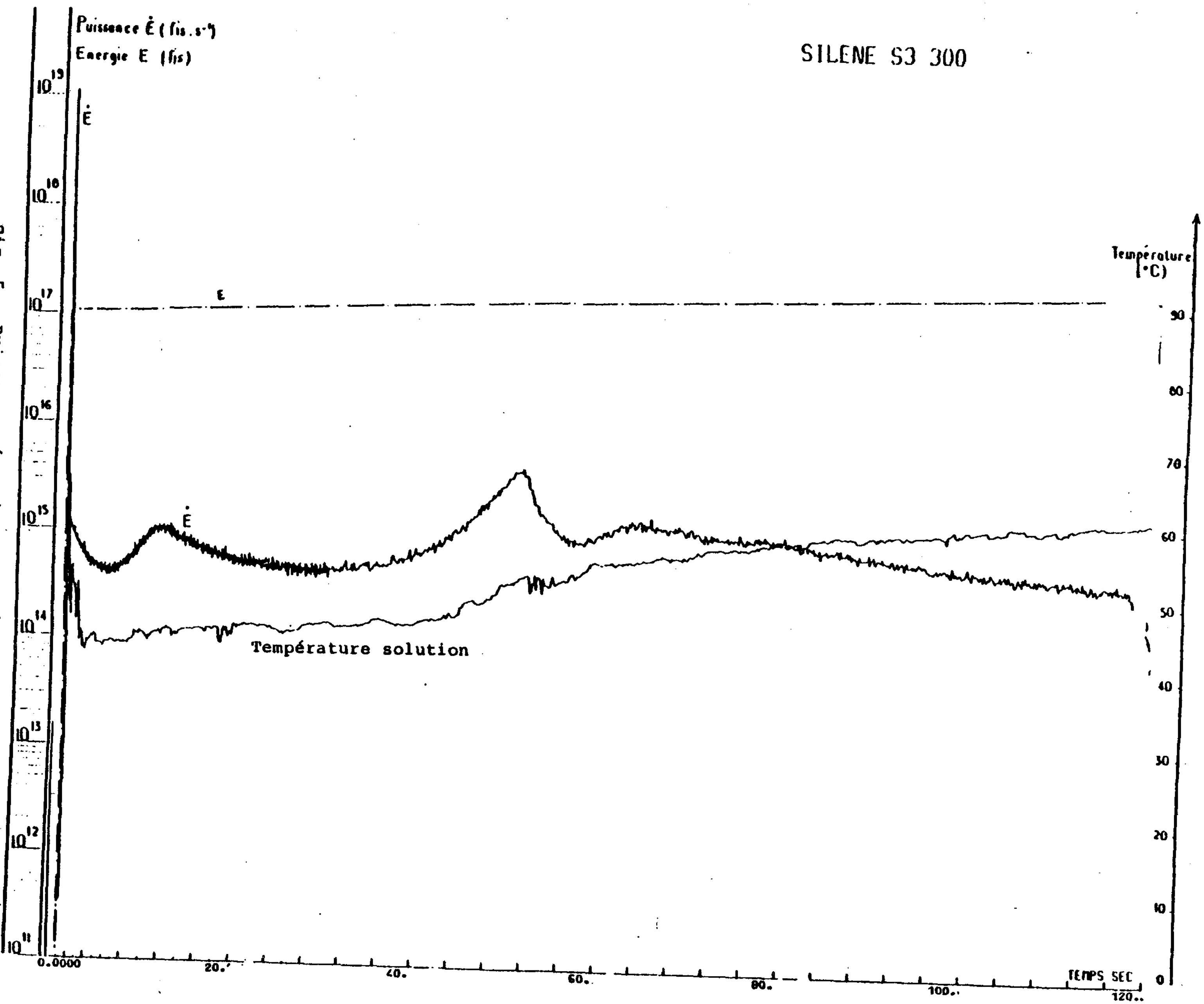


Fig. 5 Puissance, énergie et température

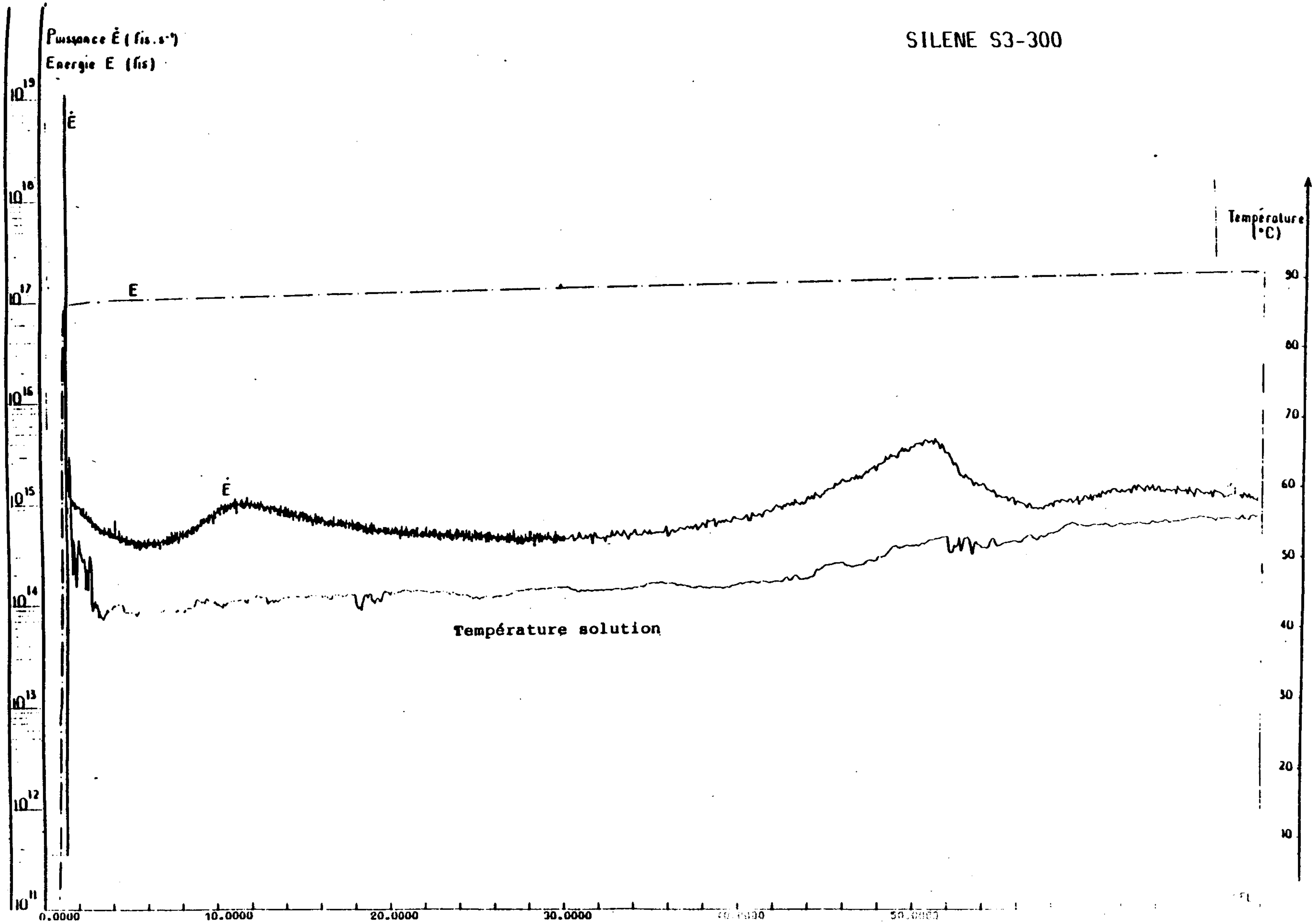


Fig. 6 Puissance, énergie et température (échelle dilatée)

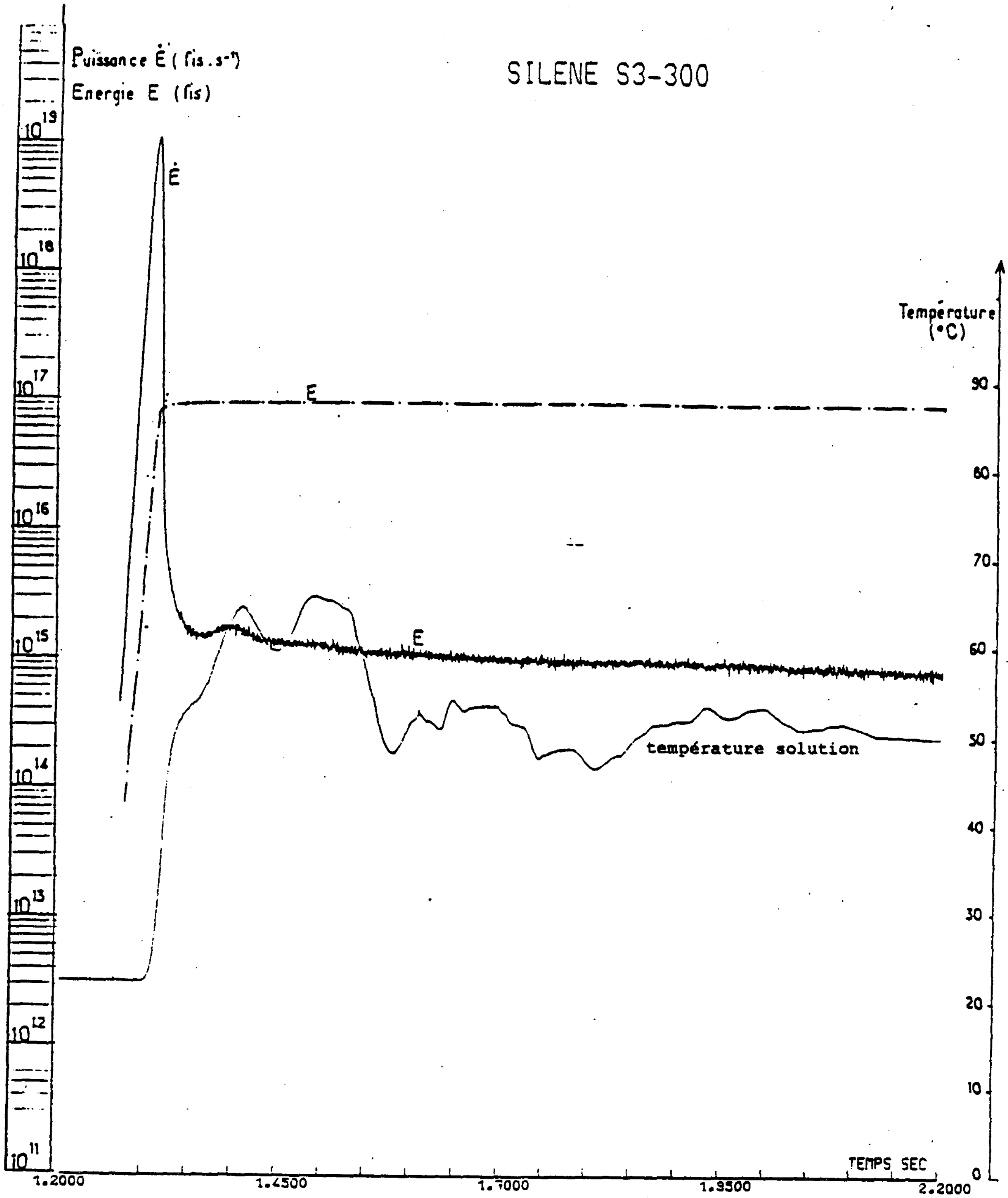
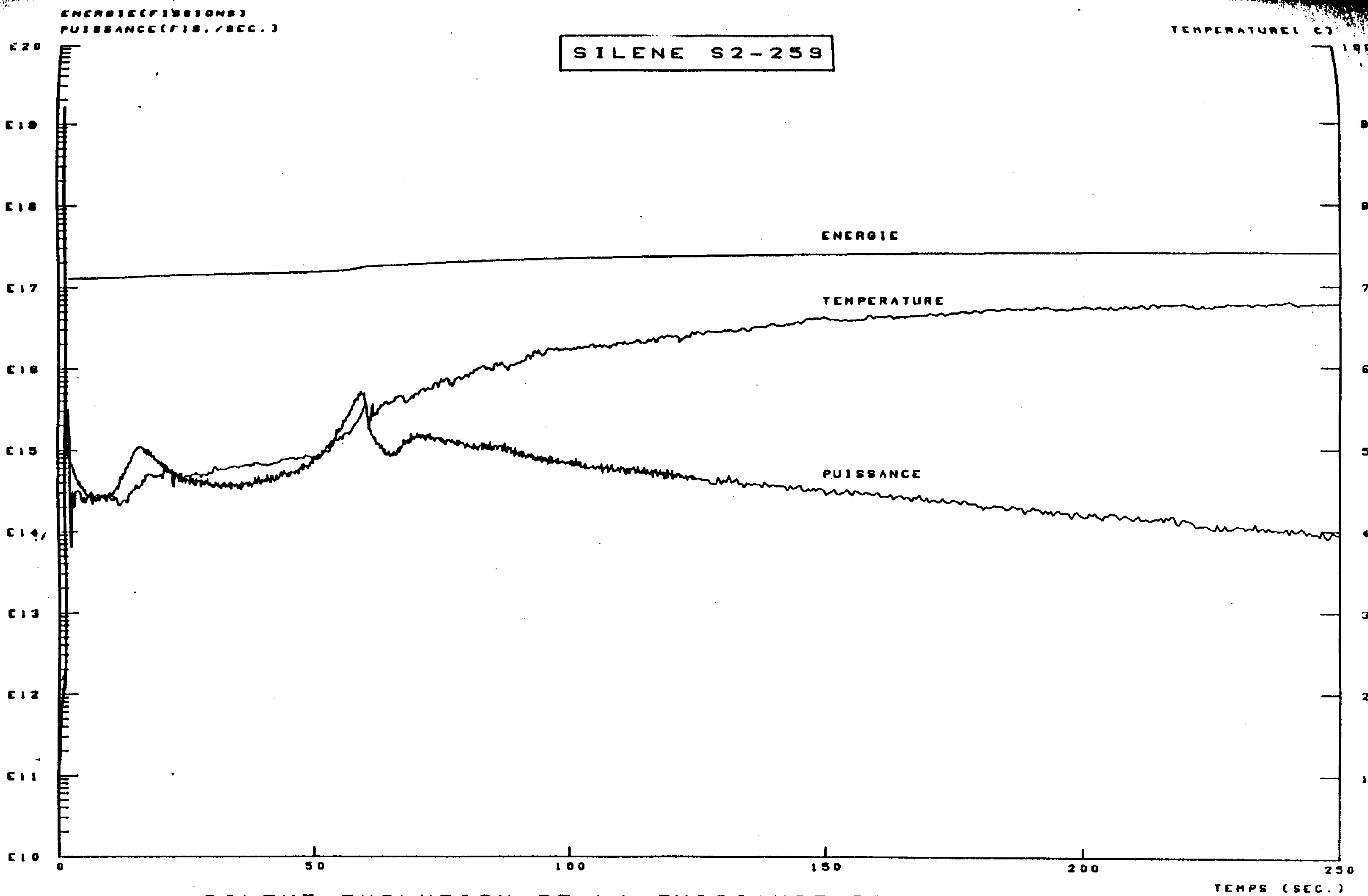
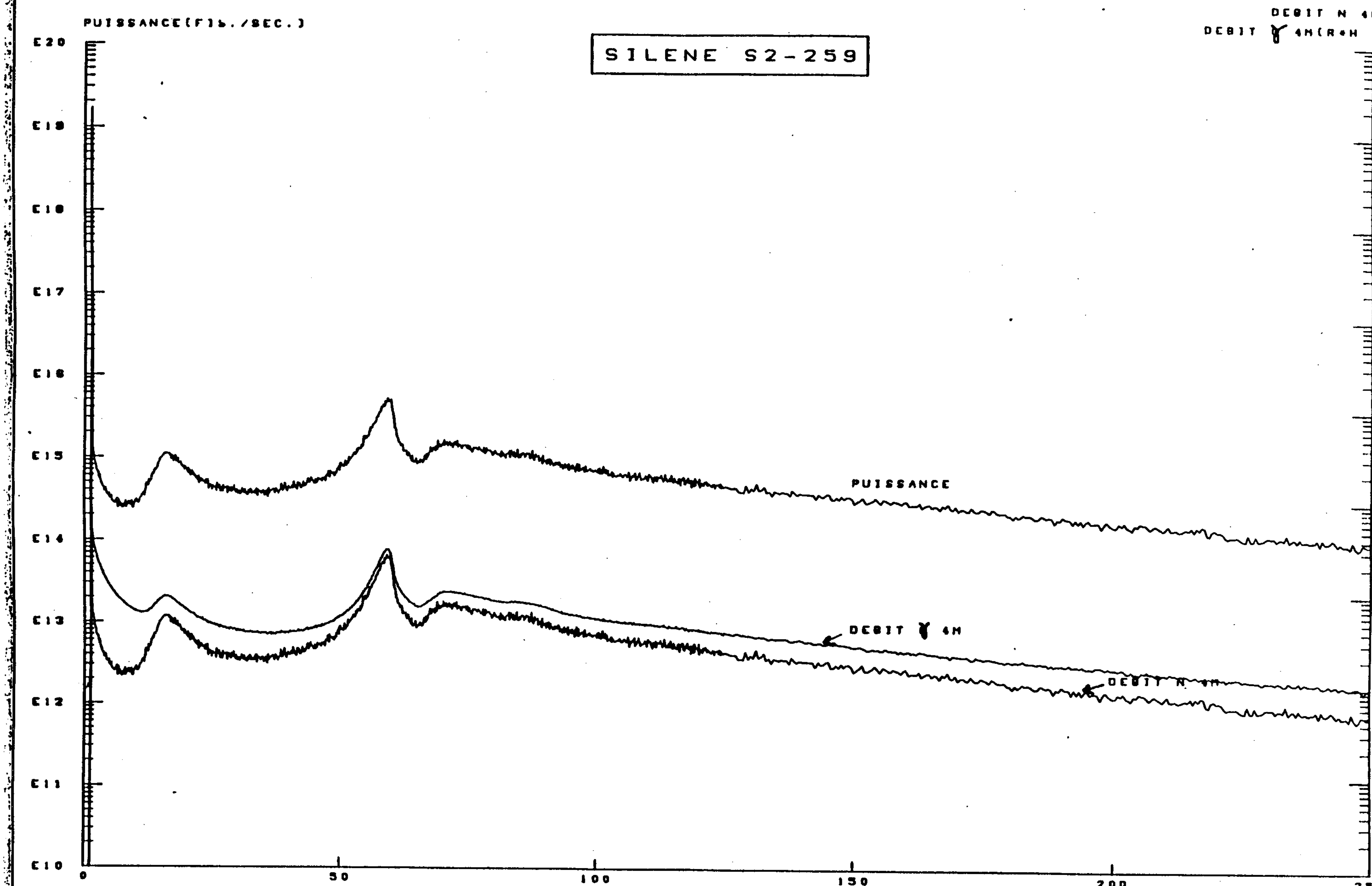


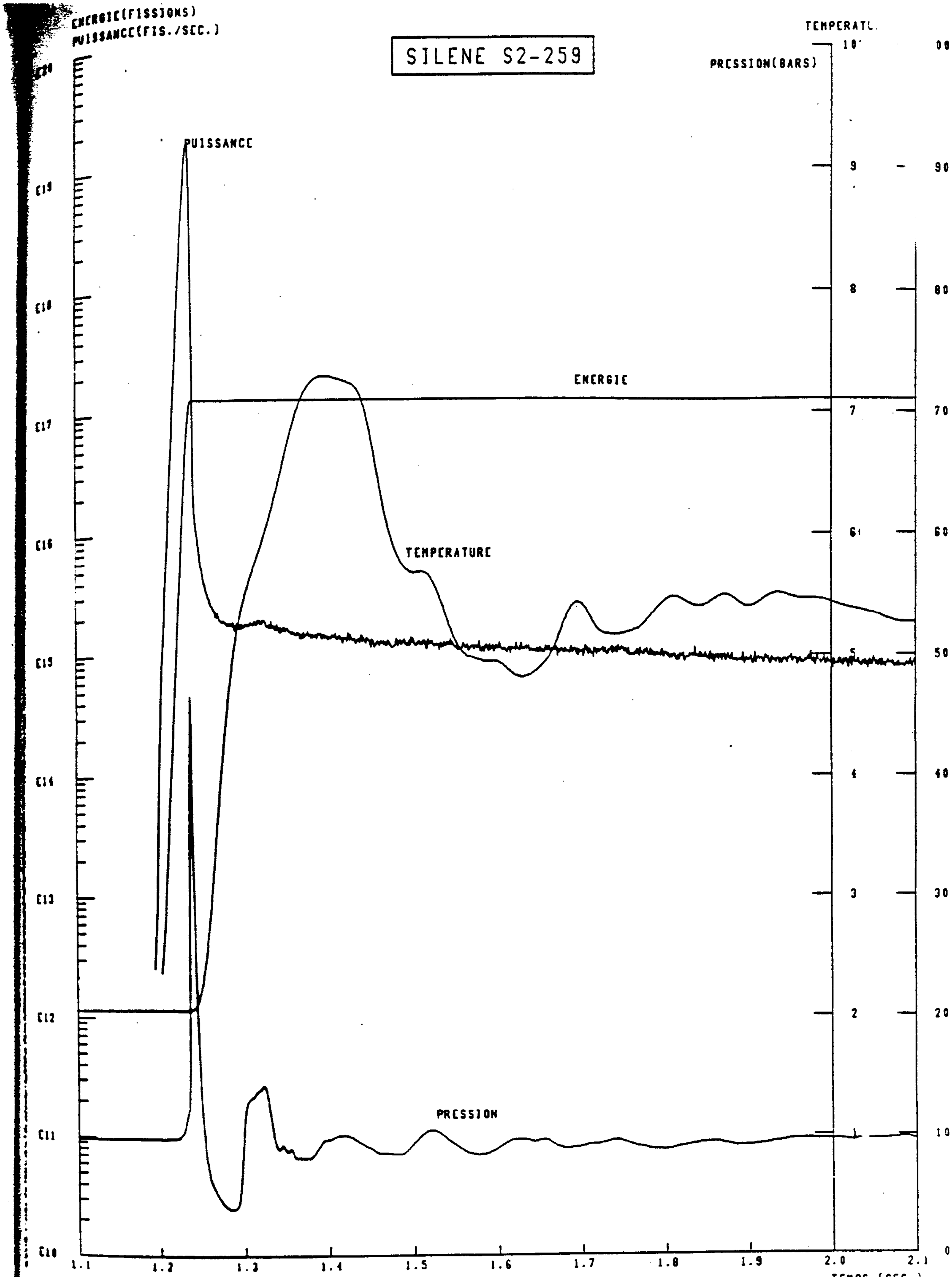
Fig. 7 Puissance, énergie et température (détail 1er pic)



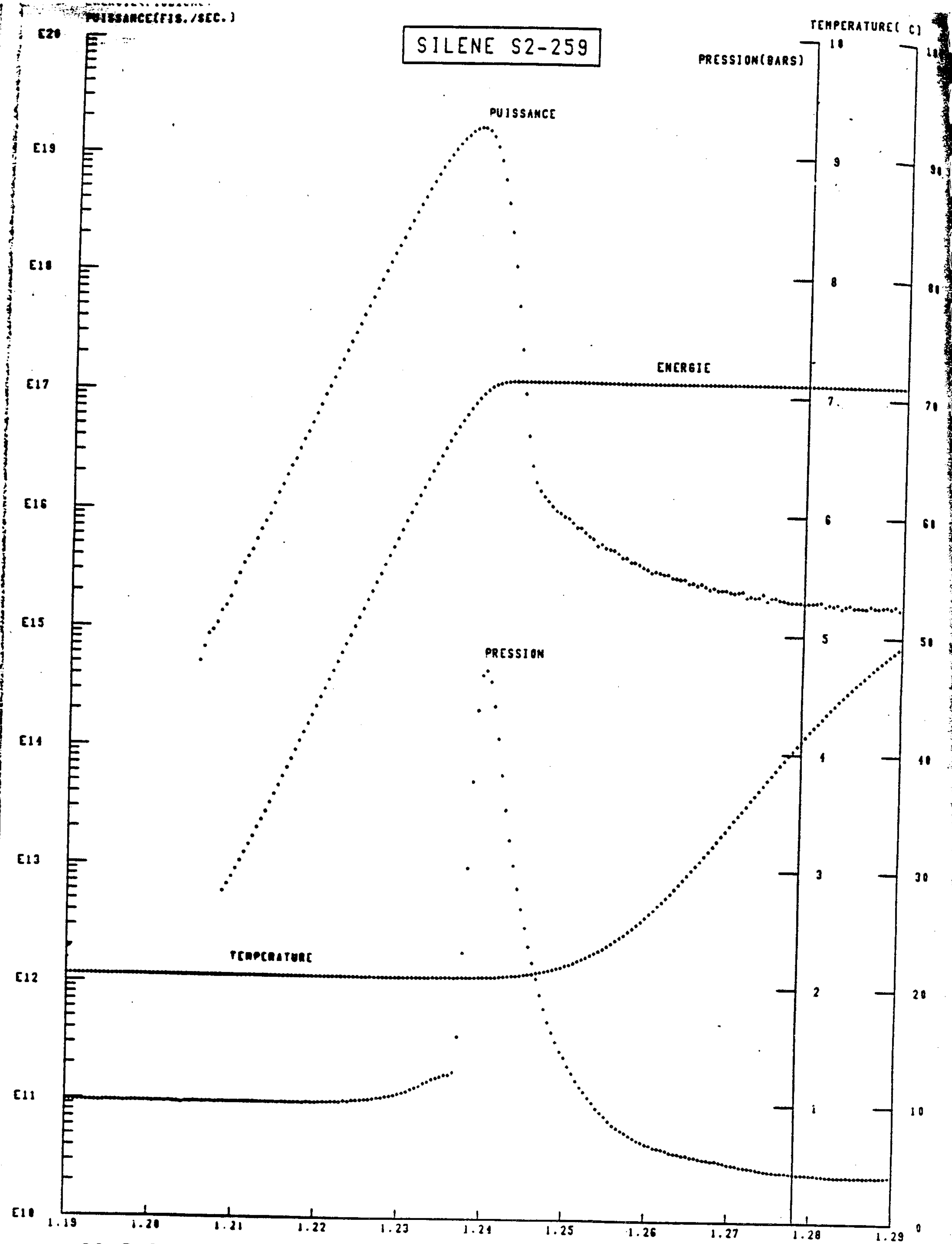
SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE
LA TEMPERATURE AU SEIN DU REACTEUR



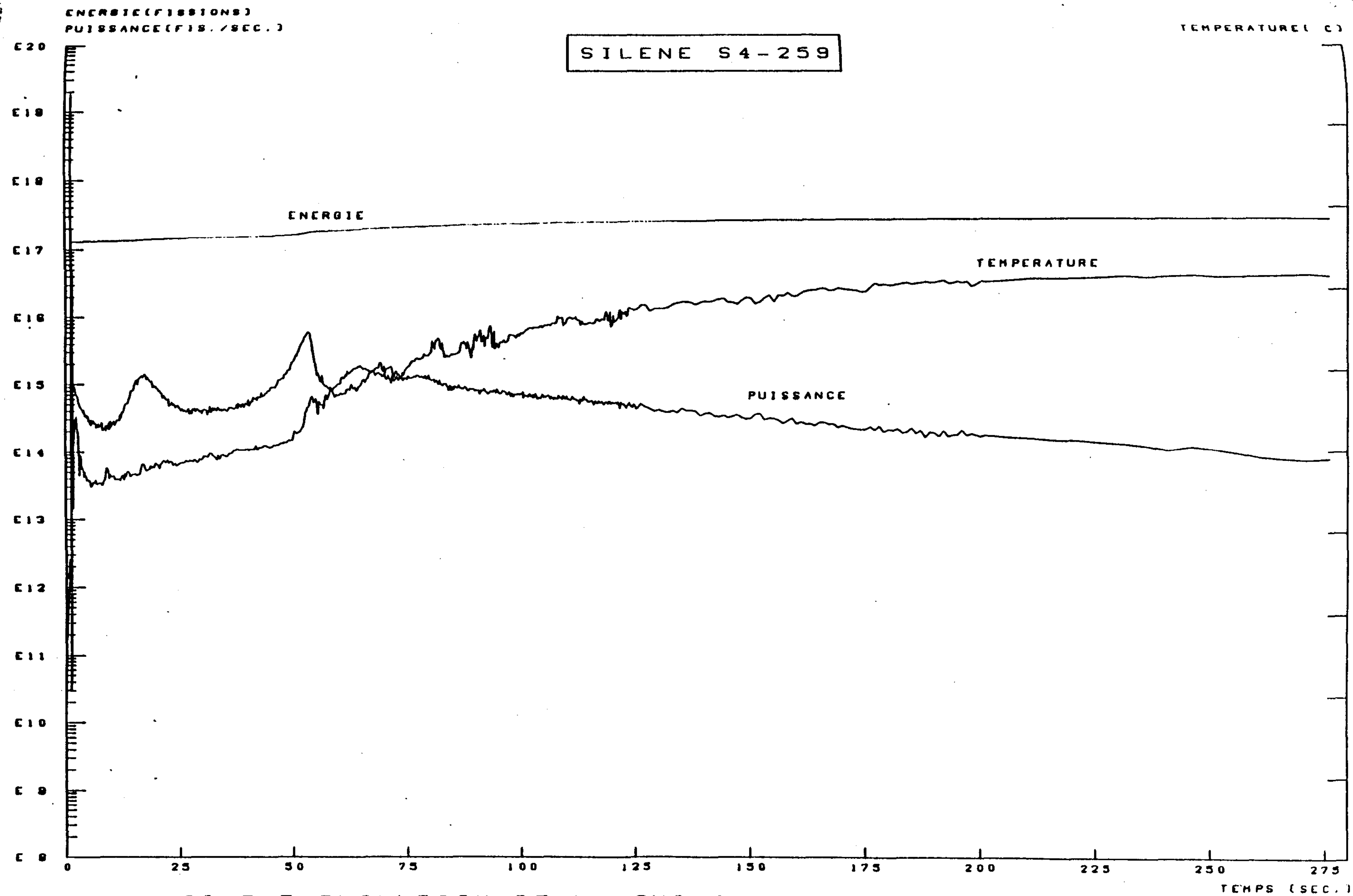
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR ET
DEBITS DE DOSES N ET GAMMA A 4M DU REACTEUR



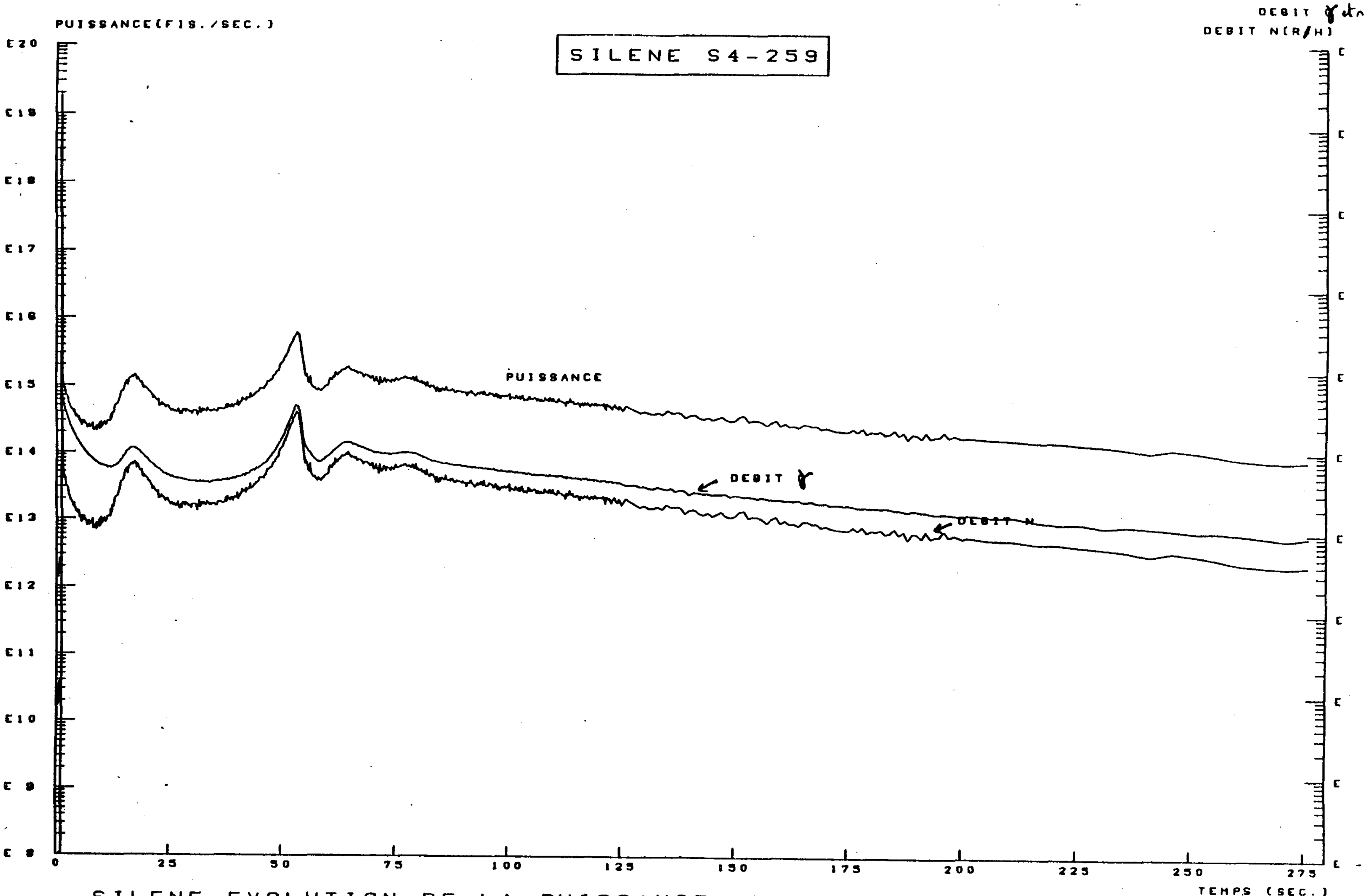
SILENE-EVOLUTION DE LA PUISSANCE DE L ENERGIE, DE LA PRESSION
ET DE LA TEMPERATURE AU SEIN DU REACTEUR(1ER PIC)



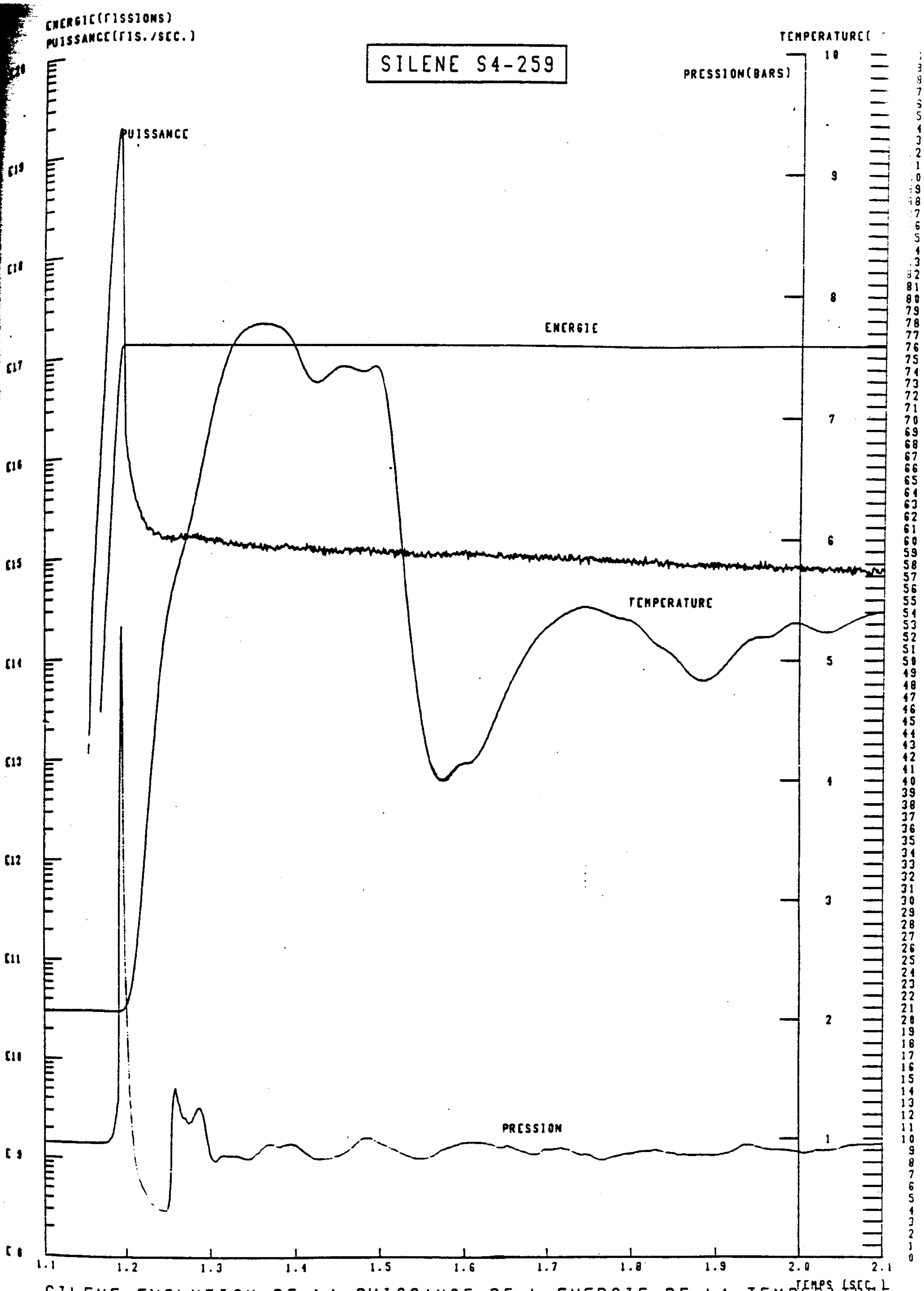
SILENE-EVOLUTION DE LA PUISSANCE DE L ENERGIE,DE LA PRESSION
ET DE LA TEMPERATURE AU SEIN DU REACTEUR(1ER PIC DETAIL)



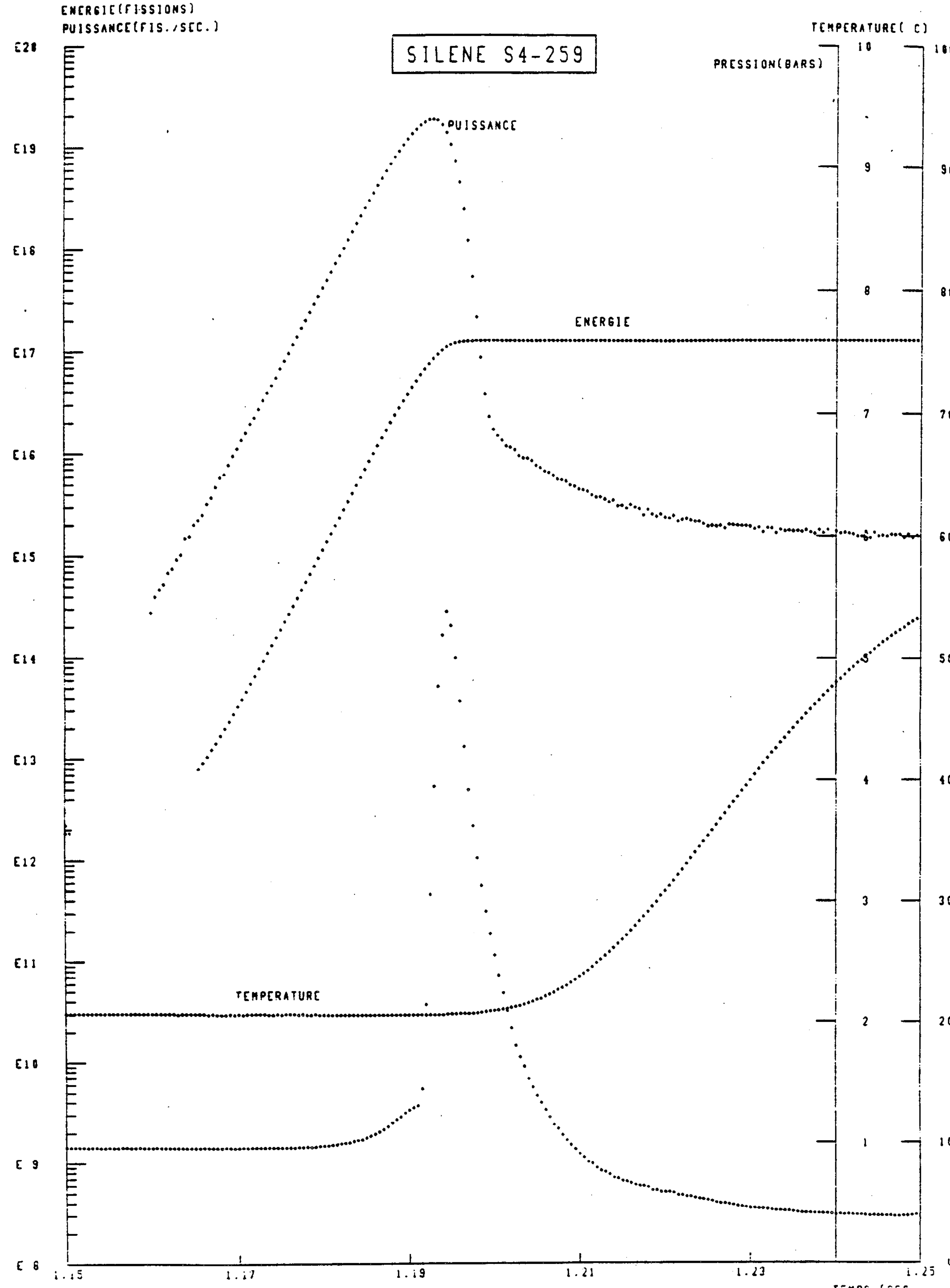
SILENE-EVOLUTION DE LA PUISSANCE.DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR(JUSQU A L ETAT D EQUILIBRE)



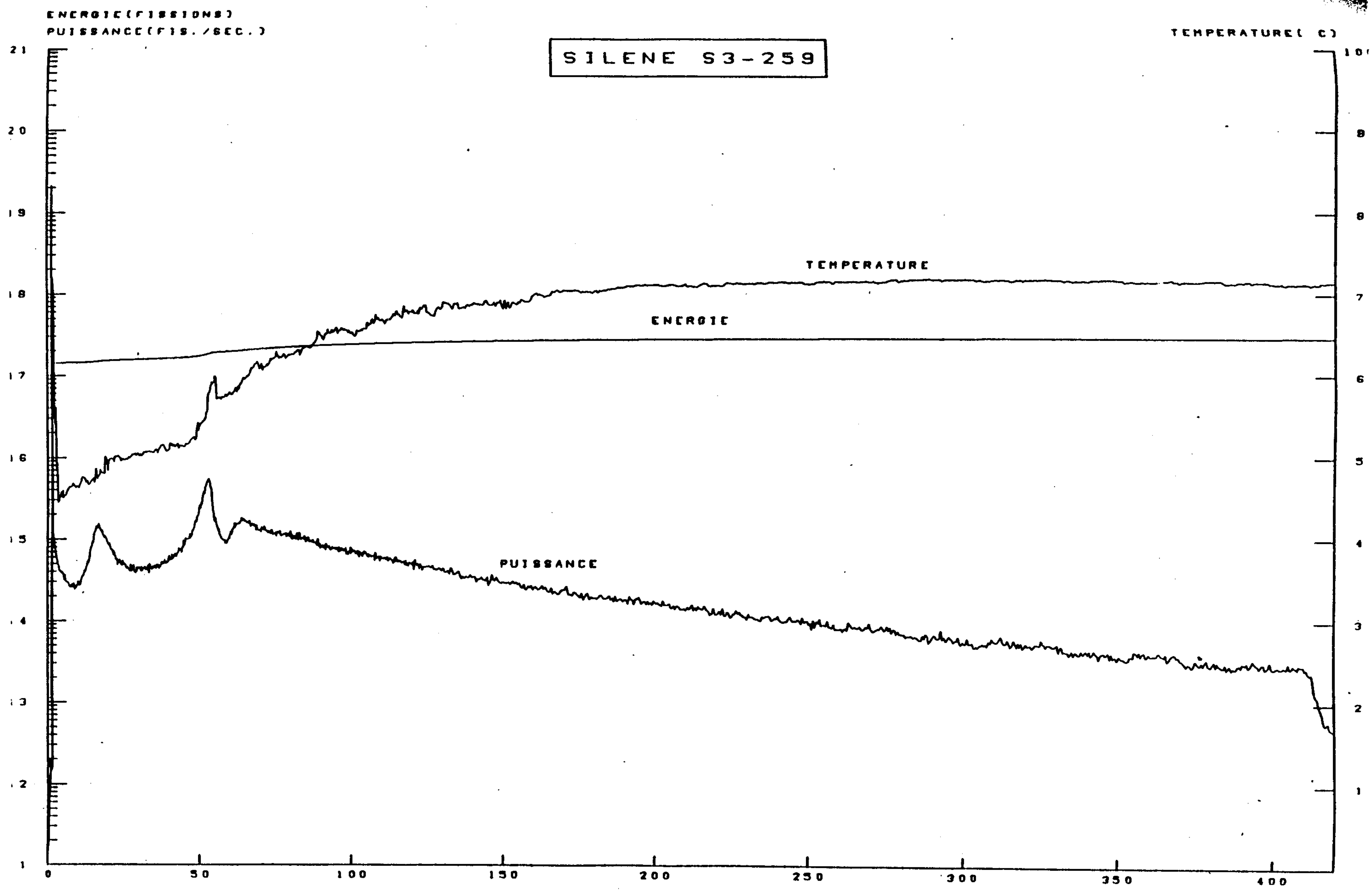
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR ET DEBITS DE DOSES N ET G A 4M DU REACTEUR.(JUSQU A L ETAT D EQUILIBRE)



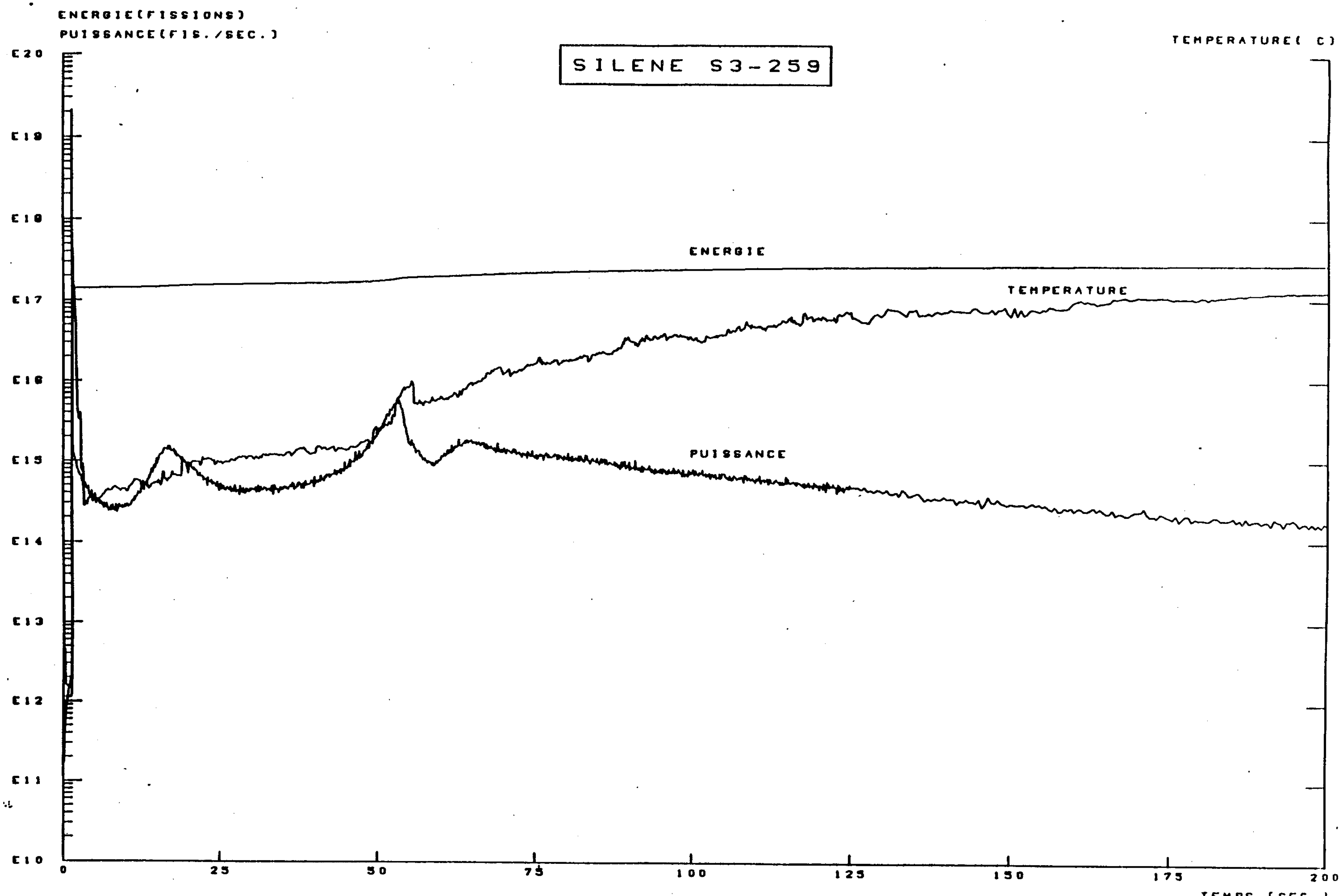
SILENE-EVOLUTION DE LA PUISSANCE,DE L ENERGIE DE LA TEMPERATURE
DE LA PRESSION AU SEIN DU REACTEUR(1ER PIC)



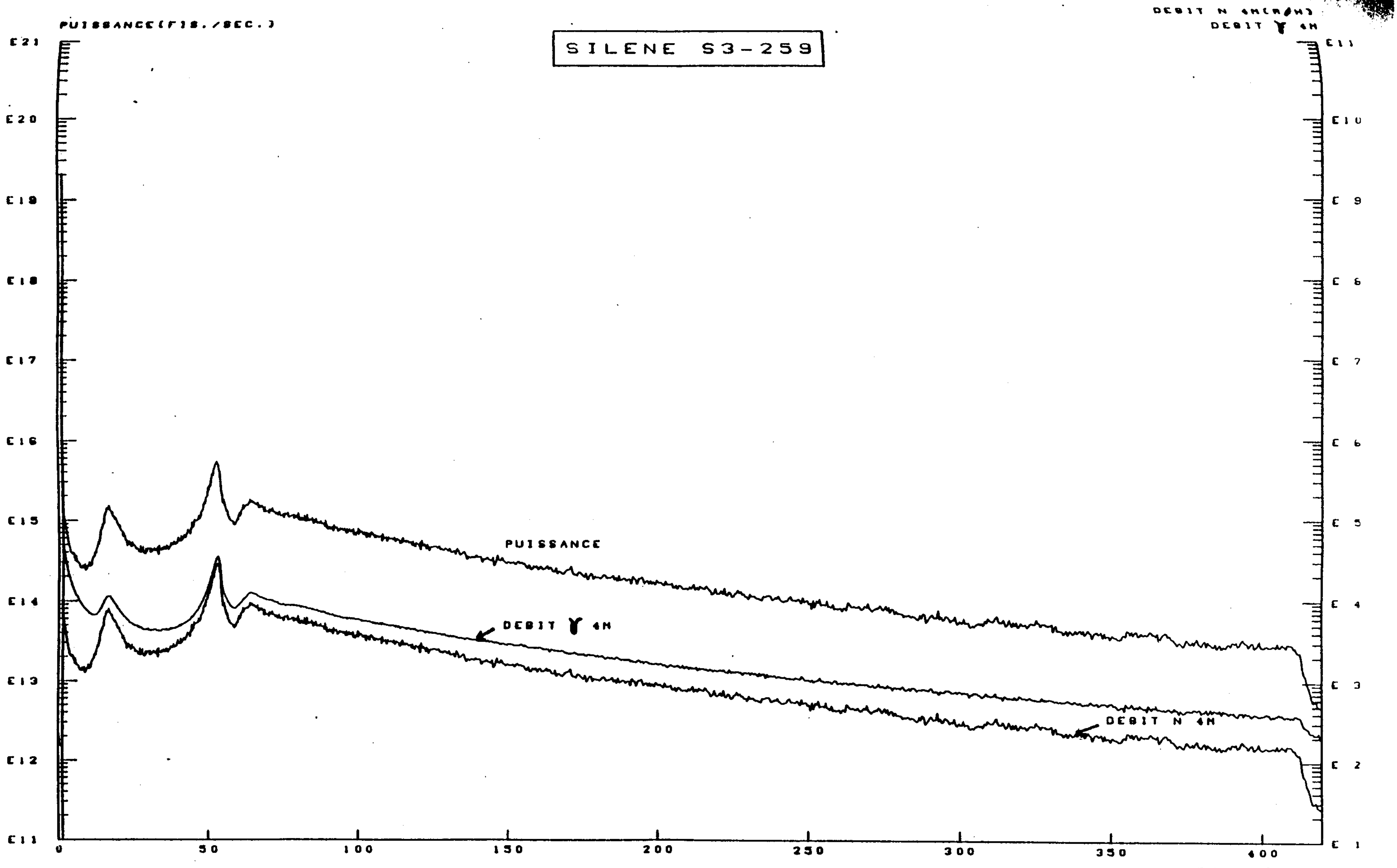
SILENE-EVOLUTION DE LA PUISSANCE DE L ENERGIE



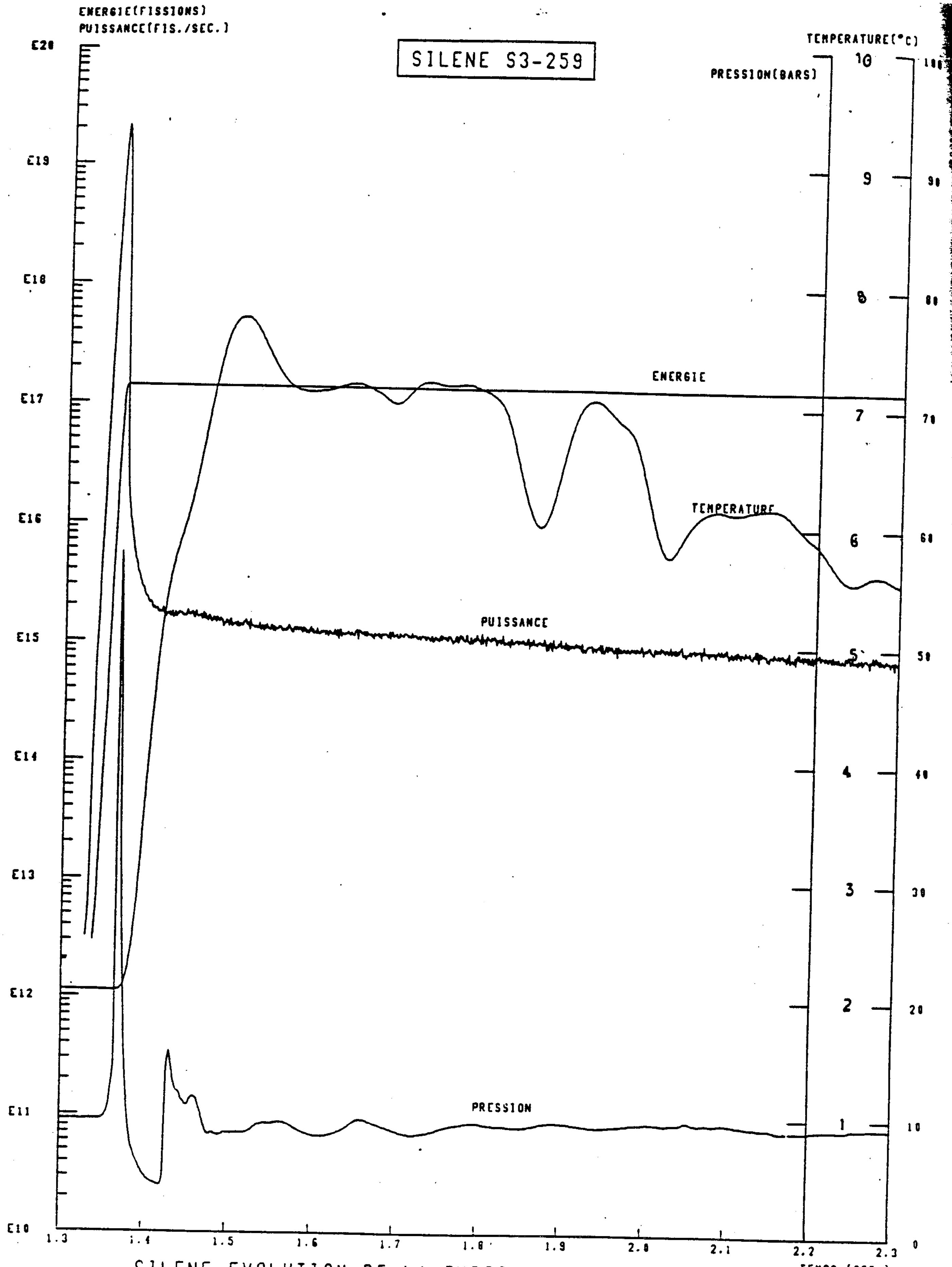
SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



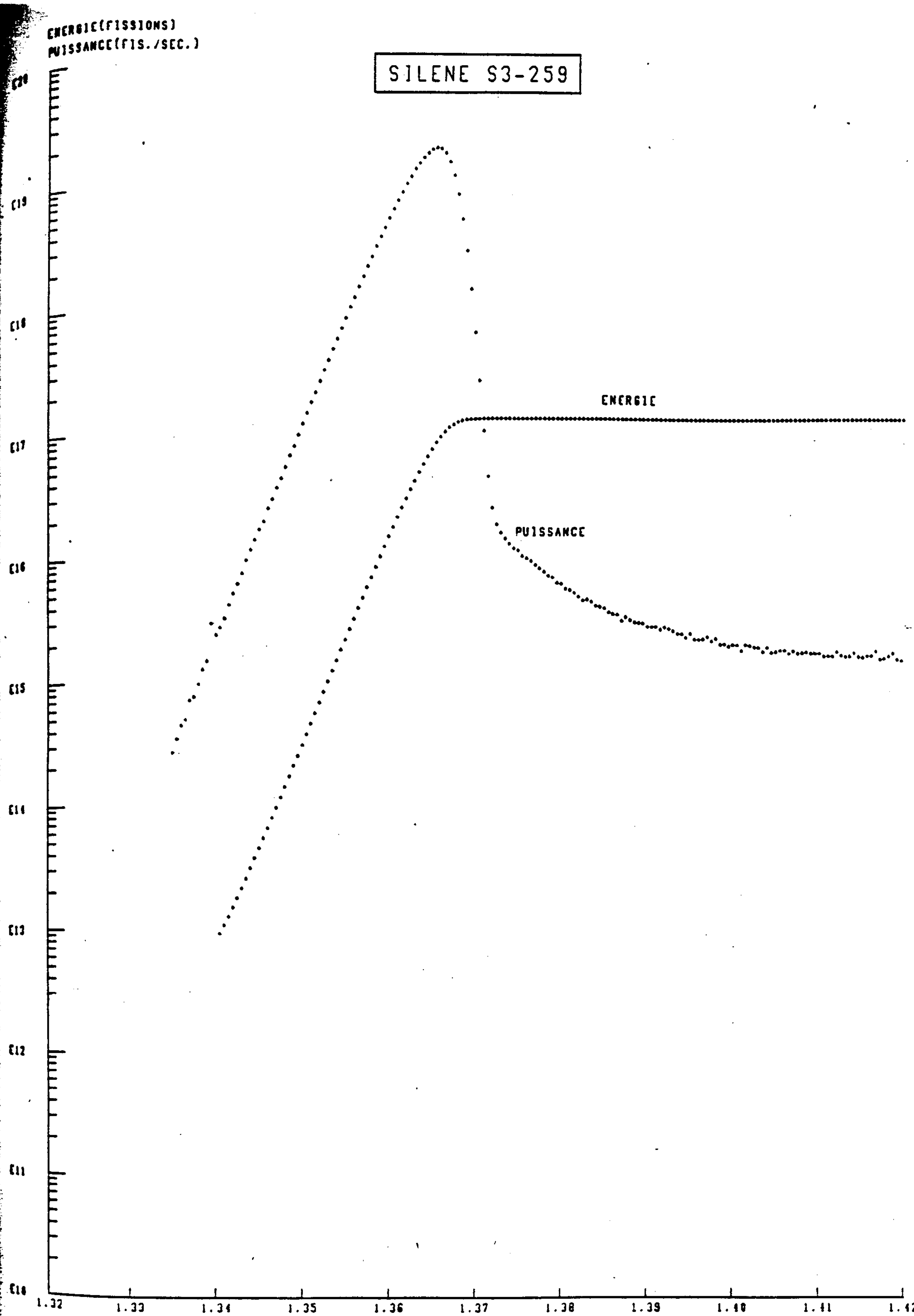
SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR(JUSQU A ETAT D EQUILIBRE)



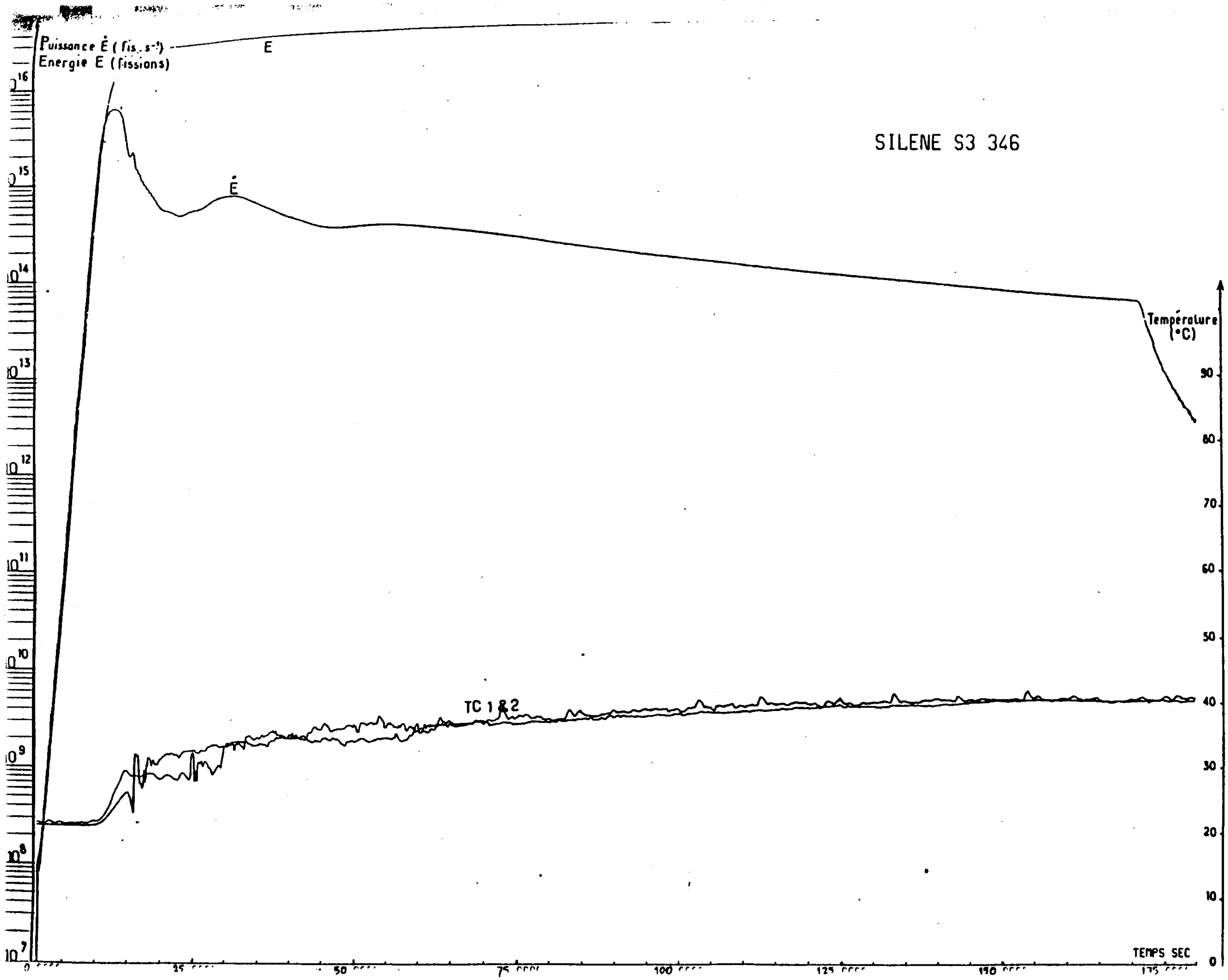
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR, ET DEBITS DE DOSES N ET G A 4M DU REACTEUR

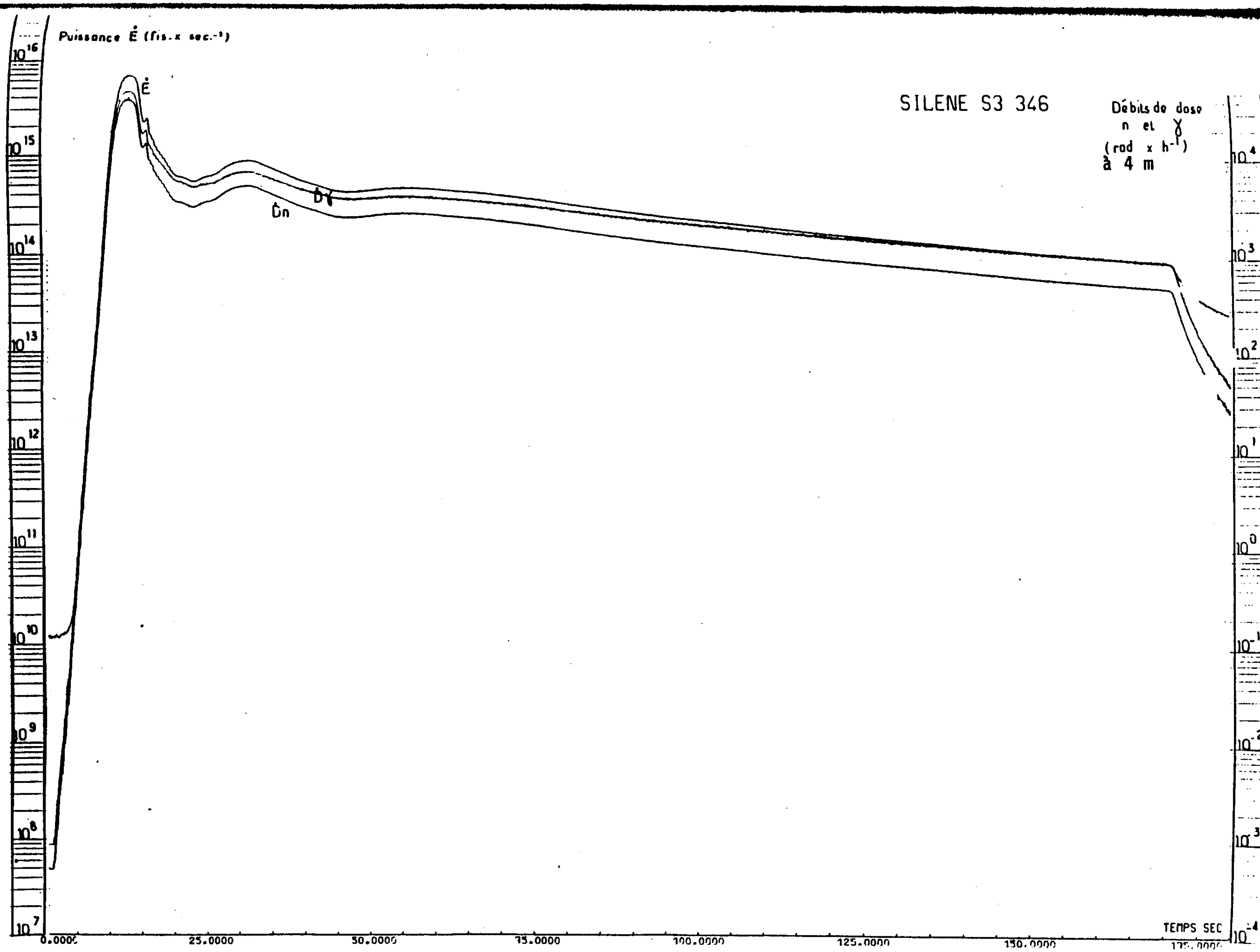


SILENE-EVOLUTION DE LA PUISSANCE,DE L ENERGIE,DE LA

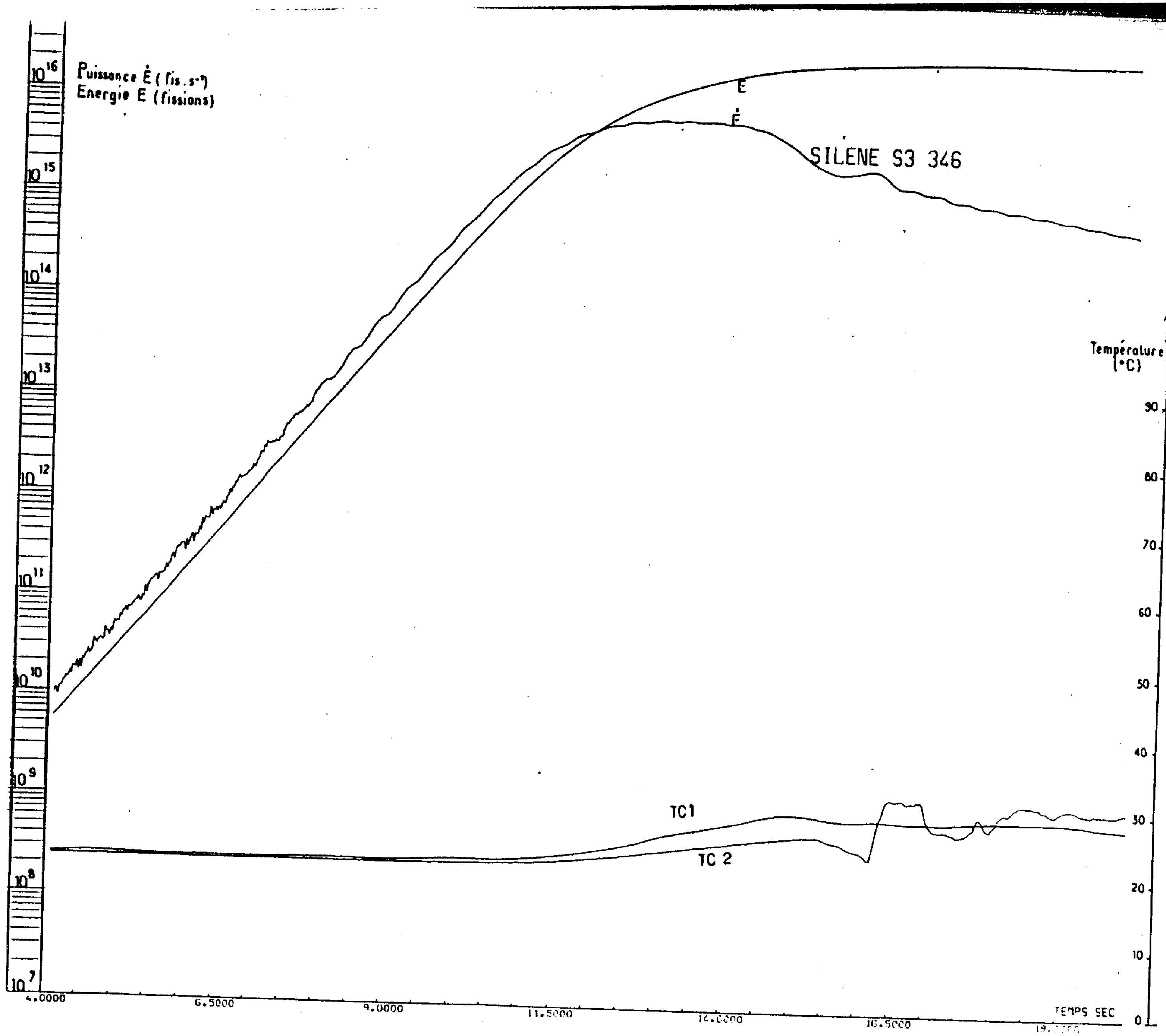


SILENE-EVOLUTION DE LA PUISSANCE ET DE L ENERGIE

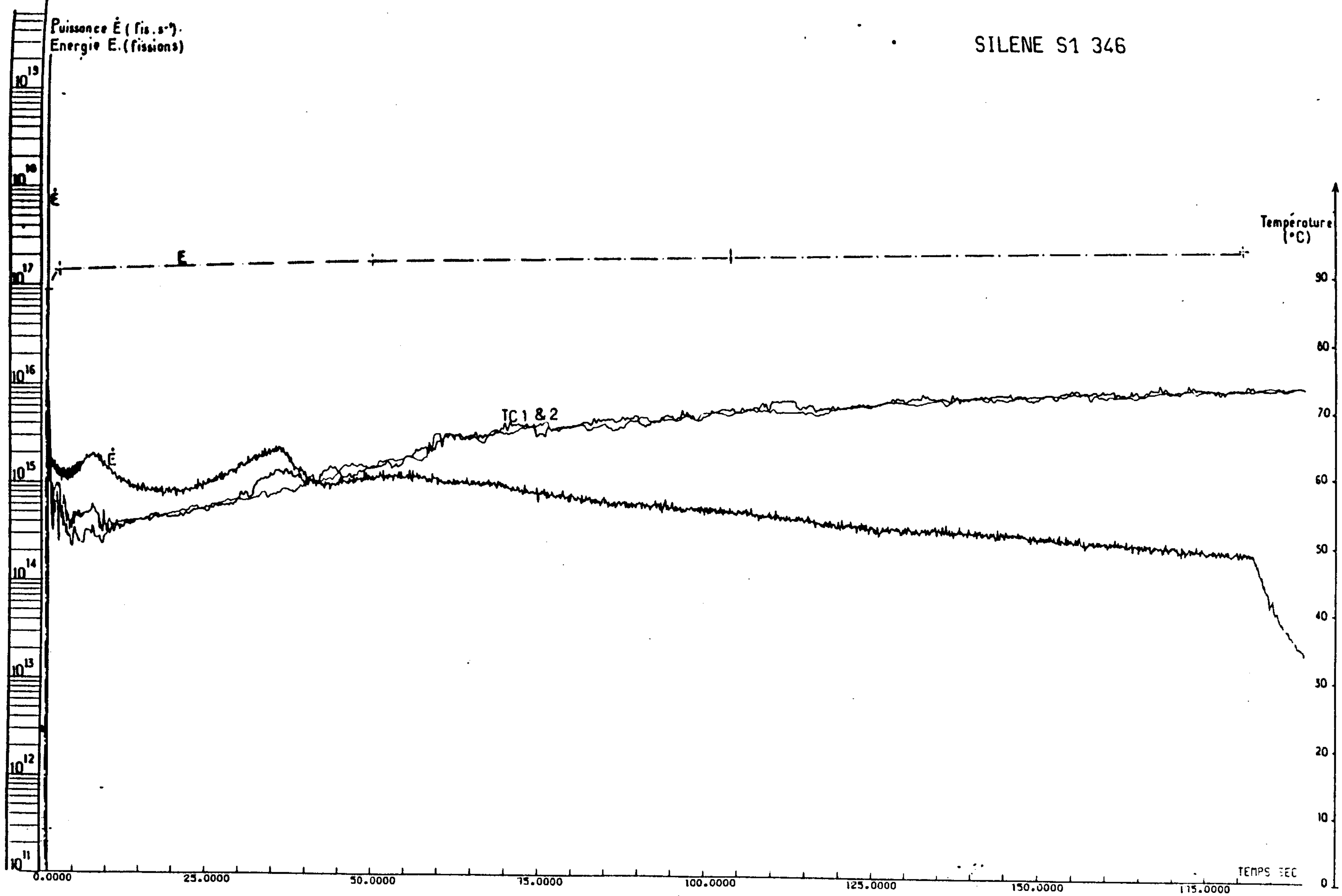

Puissance Ė (fis . s⁻¹)
Energie E (fissions)
E
SILENE S3 346
Ė
Température (°C)
TC 1 & 2
TEMPS SEC
0
25
50
75
100
125
150
175
10
20
30
40
50
60
70
80
90

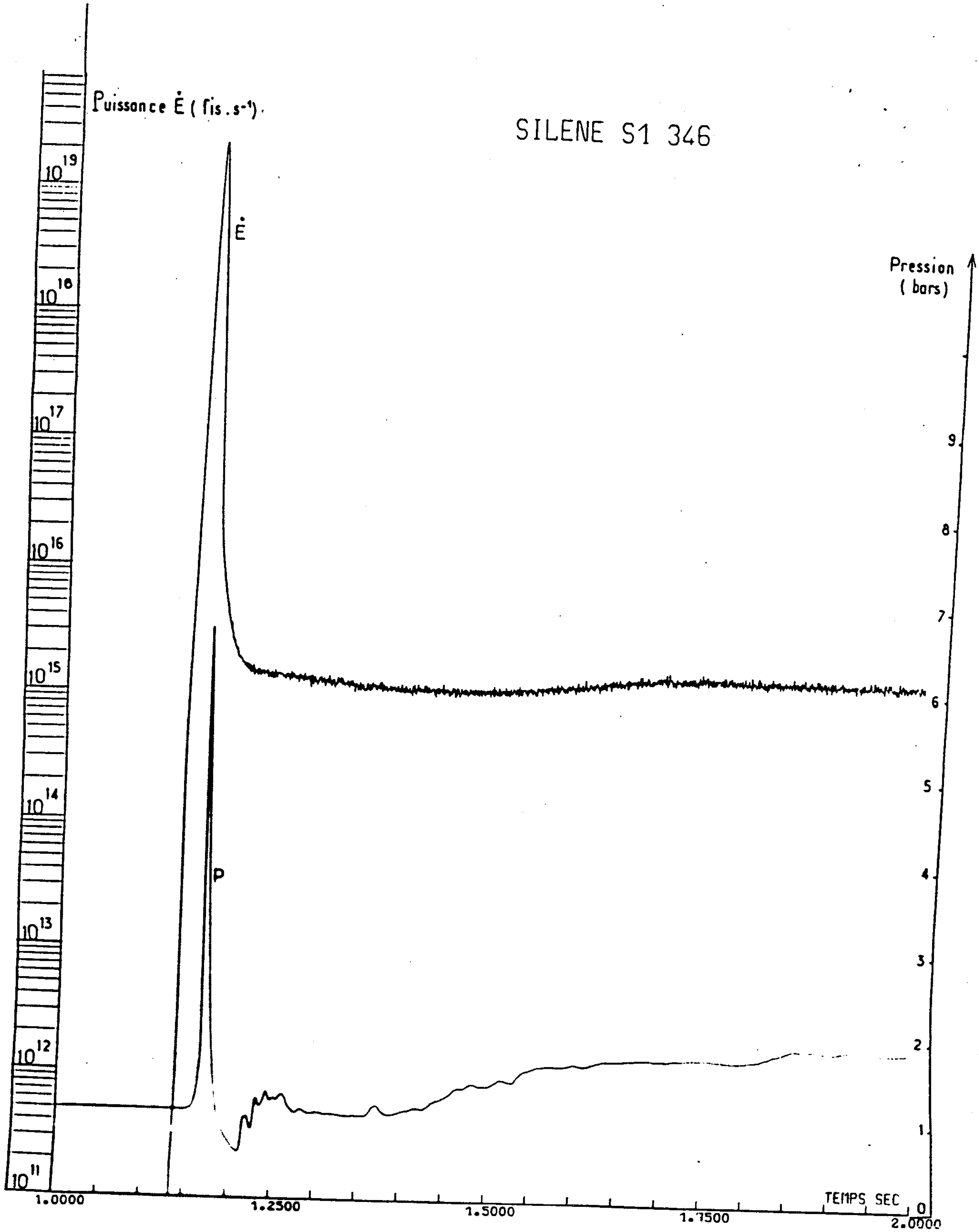


Puissance Ė (fis. x sec.⁻¹)
Ė
SILENE S3 346
Débits de dose
n et γ
(rad x h⁻¹)
à 4 m
Ḋγ
Ḋn
10¹⁶
10¹⁵
10¹⁴
10¹³
10¹²
10¹¹
10¹⁰
10⁹
10⁸
10⁷
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
0.0000
25.0000
50.0000
75.0000
100.0000
125.0000
150.0000
TEMPS SEC

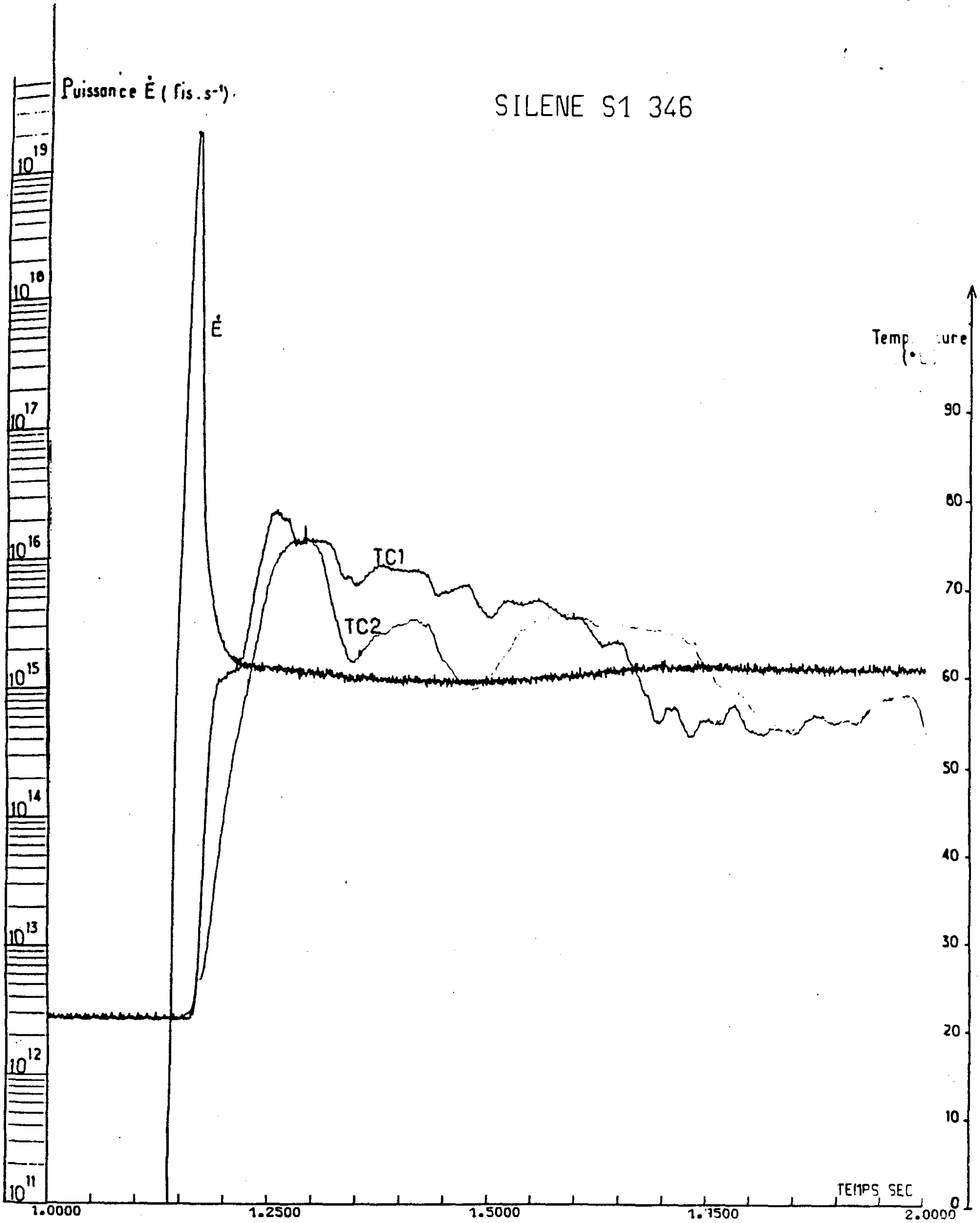


Puissance Ė (fis.s⁻¹)
Energie E (fissions)
E
Ė
SILENE S3 346
Température (°C)
TC1
TC 2
TEMPS SEC
4.0000
6.5000
9.0000
11.5000
14.0000
16.5000

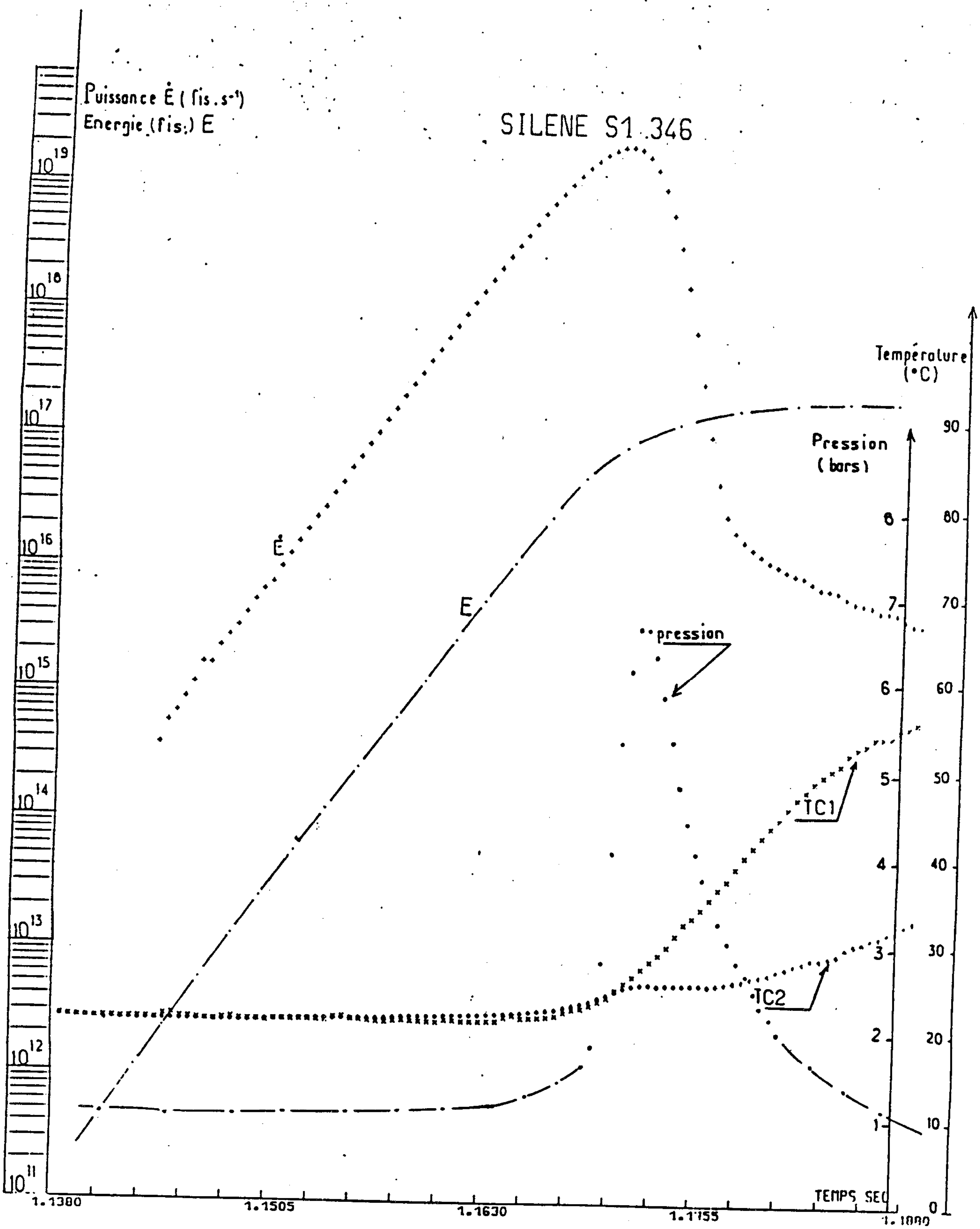

SILENE S1 346
Puissance Ė (fis.s⁻¹)
Energie E. (fissions)
Ė
E
TC 1 & 2
Température (°C)
TEMPS SEC
0.0000
25.0000
50.0000
75.0000
100.0000
125.0000
150.0000
175.0000



SILENE S1 346
Puissance Ė (fis.s⁻¹)
Ė
P
Pression (bars)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^12
10^11
0
1
2
3
4
5
6
7
8
9
1.0000
1.2500
1.5000
1.7500
2.0000
TEMPS SEC



Puissance Ė (fis.s⁻¹)
SILENE S1 346
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^12
10^11
Ė
TC1
TC2
90
80
70
60
50
40
30
20
10
0
1.0000
1.2500
1.5000
2.0000
TEMPS SEC



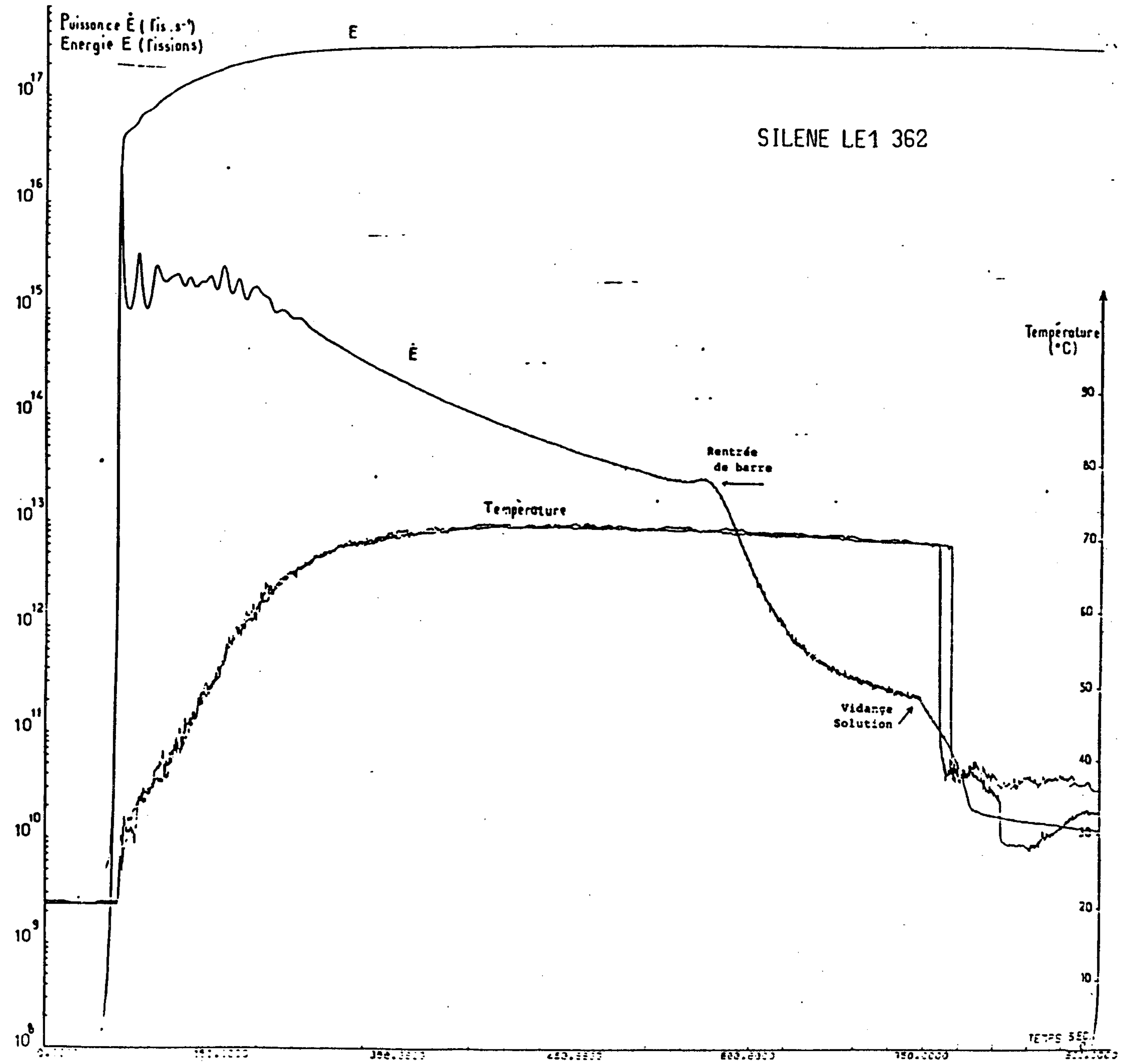
Puissance Ė (fis.s⁻¹)
Energie (fis.) E
SILENE S1 346
Ė
E
pression
TC1
TC2
Température (°C)
Pression (bars)
TEMPS SEC
1.1380
1.1505
1.1630
1.1755
1.1880

SILENE

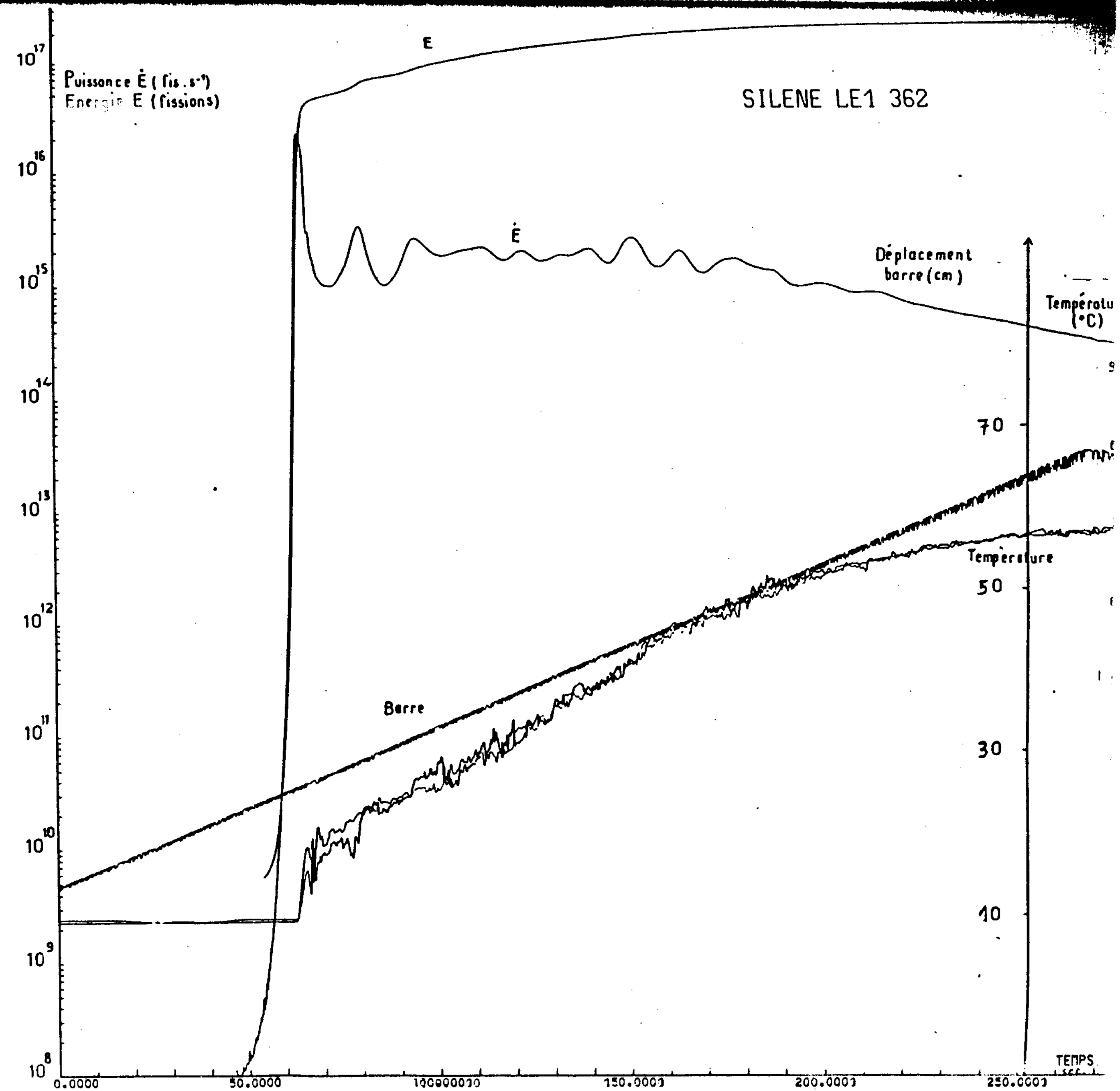
EXPERIENCES DU TYPES "EBULITION"

EXPERIENCE SILENE	$C_{u_{g/l}}$	$H_{c_{cm}}$	ΔH_{mm}	$H_{f_{cm}}$	V_{f_l}	1er PIC								
						T_{2_s}	$\omega_{s^{-1}}$	$\dot{E}_{fissions\ s^{-1}}$	$\hat{E}_{fissions}$	$E_{p_{1_{fissions}}}$	$E_{p_{2_{fissions}}}$	ΔP_{bar}	$\Delta k_{1_{PCM}}$	Δk_{1_S}
LE1-175	71.4	36.79	90	45.79	44.41	0.015	46	$4.2\ 10^{17}$	$1.7\ 10^{17}$	$4.2\ 10^{16}$	$4.6\ 10^{16}$		960	1.21
LE1-176	69.8	38.07	114.9	49.56	48.07	0.016	43	$4.5\ 10^{17}$	$1.8\ 10^{16}$	$3.7\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE2-176	69.8	38.07	139.9	52.06	50.49	0.018	38	$4.1\ 10^{17}$	$1.7\ 10^{16}$	$3.7\ 10^{16}$	$5.6\ 10^{16}$		930	1.17
LE2-343	70.6	37.1	140	51.1	49.57	0.016	42.5	$3.8\ 10^{17}$	$1.6\ 10^{16}$	$3.2\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE1-281	70.9	37.42	170	54.42	52.79	0.017	41	$4.2\ 10^{17}$	$1.7\ 10^{16}$	$3.8\ 10^{16}$	$5.4\ 10^{16}$		940	1.18

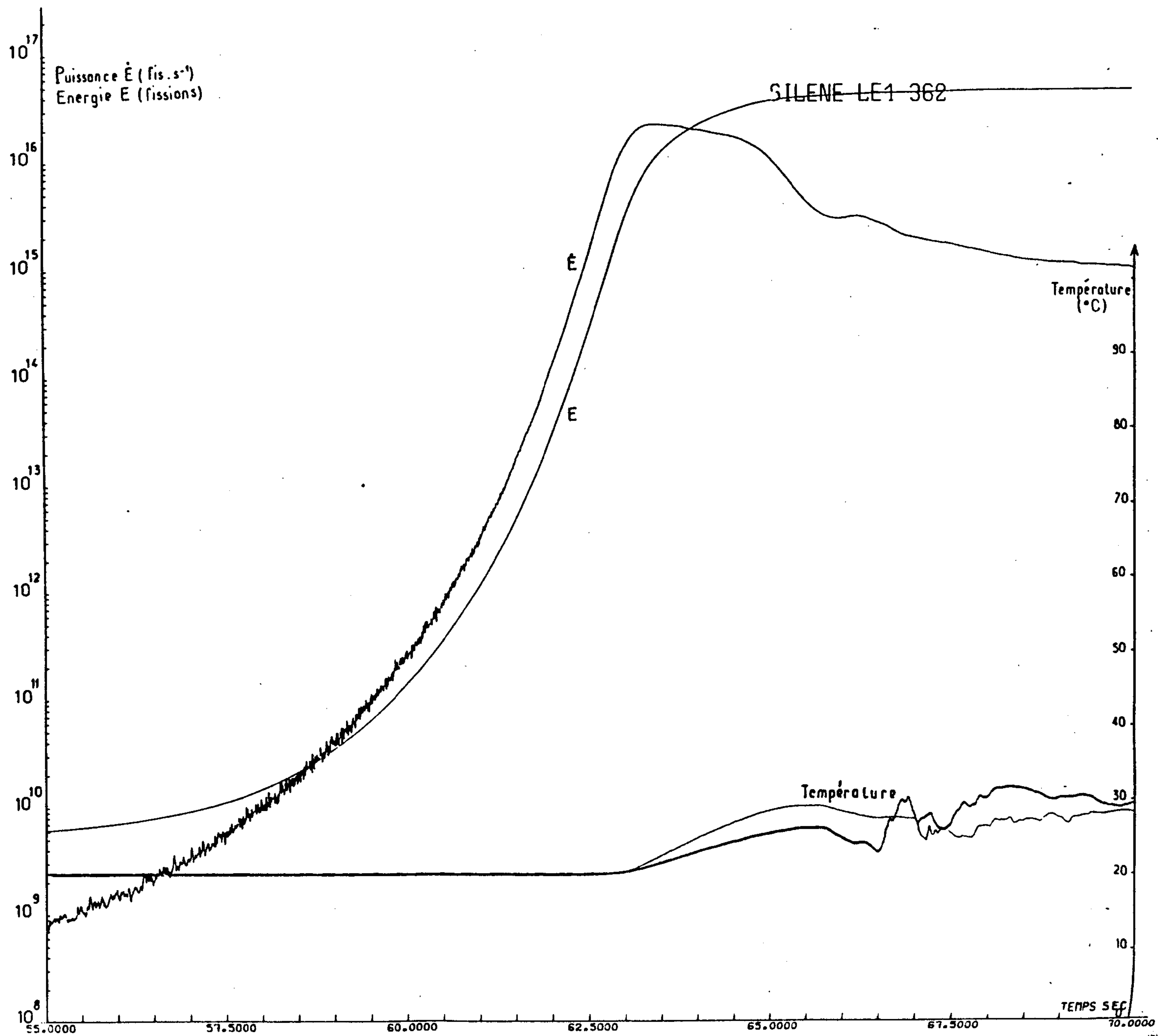
EXPERIENCE SILENE	TEMPERATURE		REACTIVITE POTENTIELLE		DUREE $_S$	$N_{f_{fissions}}$	SOURCE NEUTRONS	CATEGORIE
	$\Theta_{l\ °C}$	$\Delta\Theta_{°C_{max}}$	$\Delta k_{p_{pcm}}$	Δk_{p_S}				
LE1-175	19.6		4000	5.0	540	$5.4\ 10^{17}$	OUI	
LE1-176	18.8		4100	5.2	720	$6.9\ 10^{17}$	OUI	5.6
LE2-176	18.8		4800	6.0	900	$7.4\ 10^{17}$	OUI	5.6
LE2-343	22.4		5100	6.4	700	$8.7\ 10^{17}$	OUI	5.6
LE1-281	21		5700	7.2	600	$8.6\ 10^{17}$	OUI	5.6



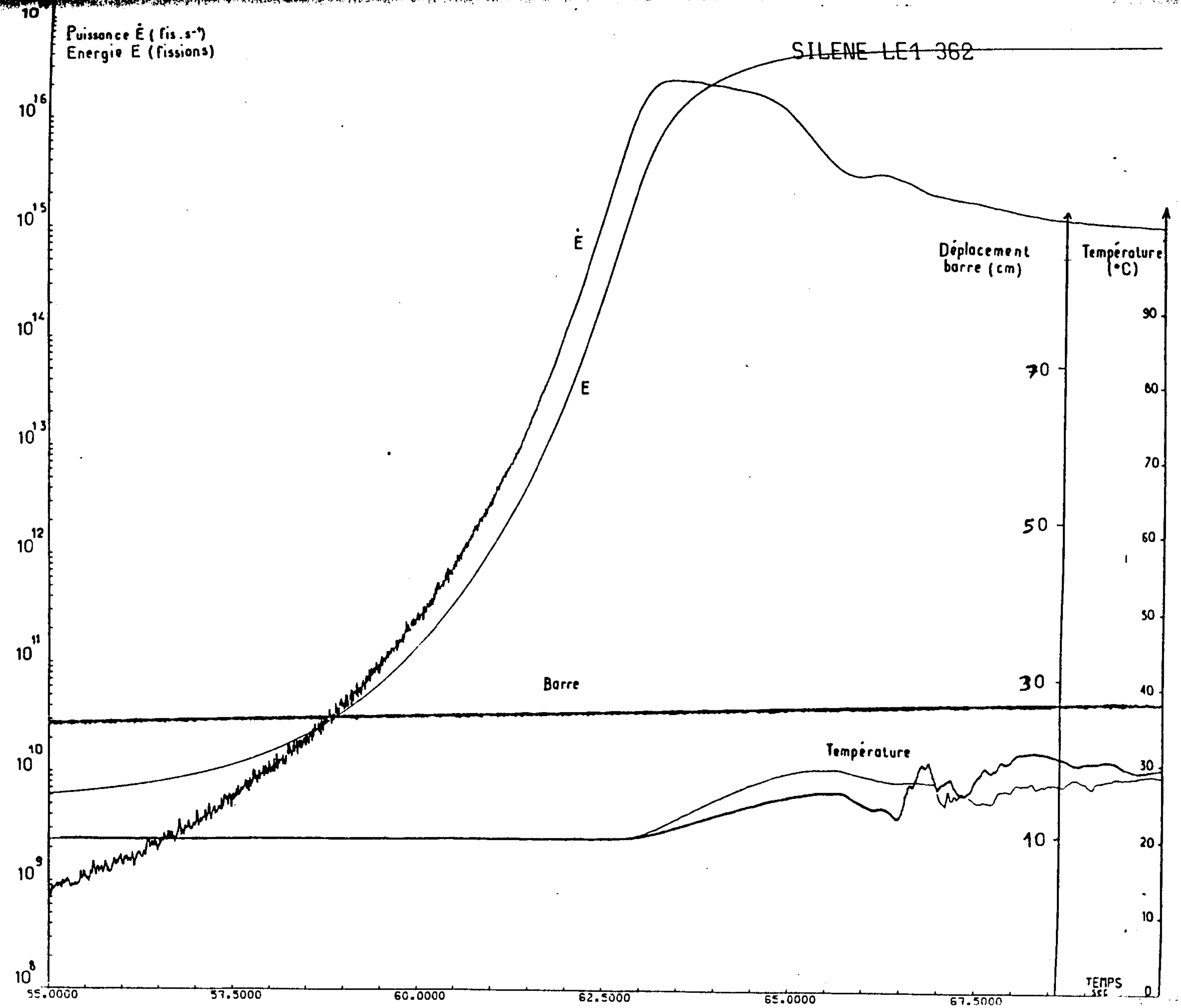
Puissance Ė (fis.s-1)
Energie E (fissions)
E
SILENE LE1 362
Ė
Rentrée de barre
Température
Vidange Solution
Température (°C)
10^17
10^16
10^15
10^14
10^13
10^12
10^11
10^10
10^9
10^8
90
80
70
60
50
40
30
20
10



Puissance Ė (fis.s⁻¹)
Energie E (fissions)
SILENE LE1 362
E
Ė
Déplacement barre (cm)
Température (°C)
Barre
Température
TEMPS
0.0000
50.0000
100.0000
150.0000
200.0000
250.0000
70
50
30
10

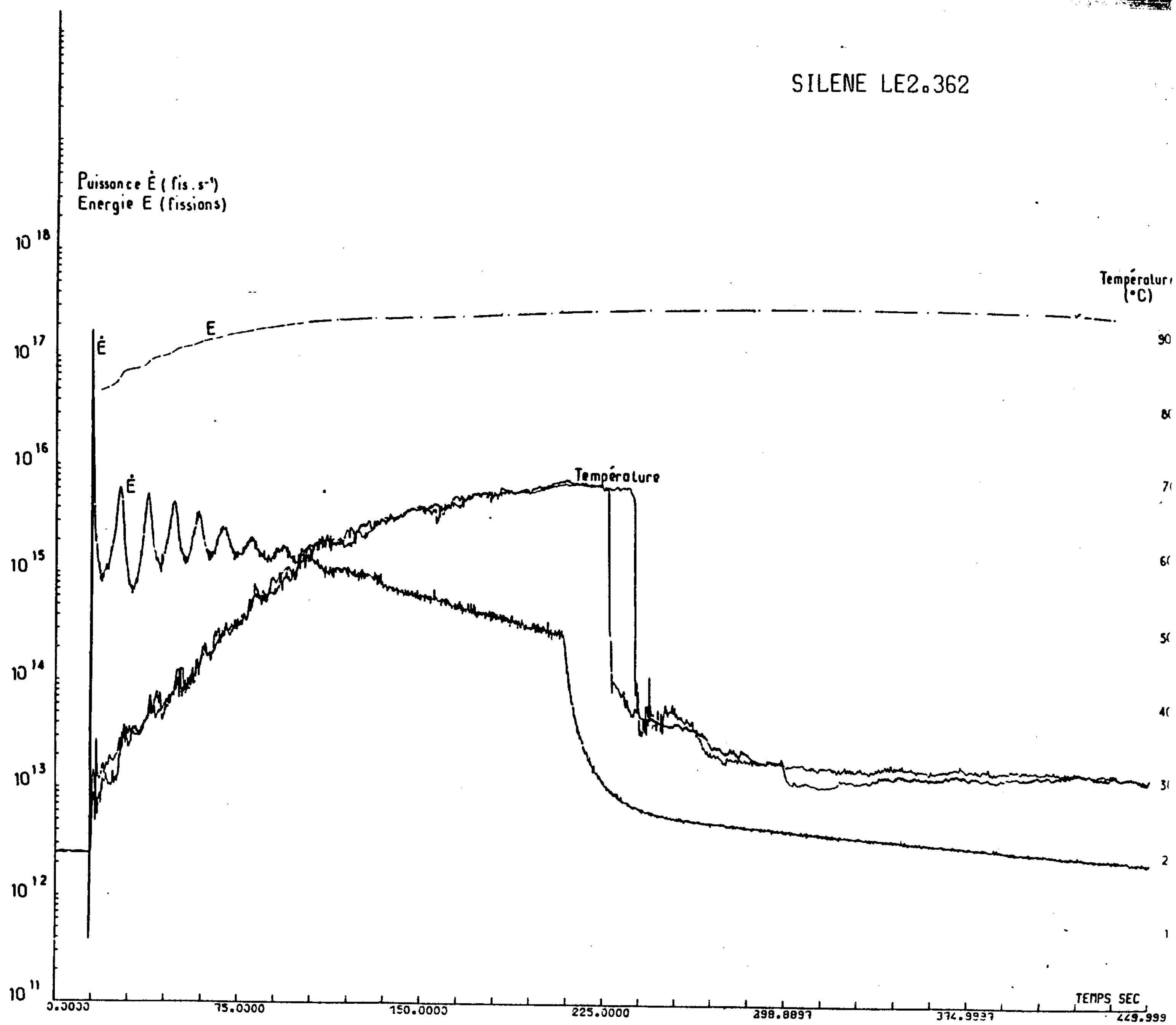


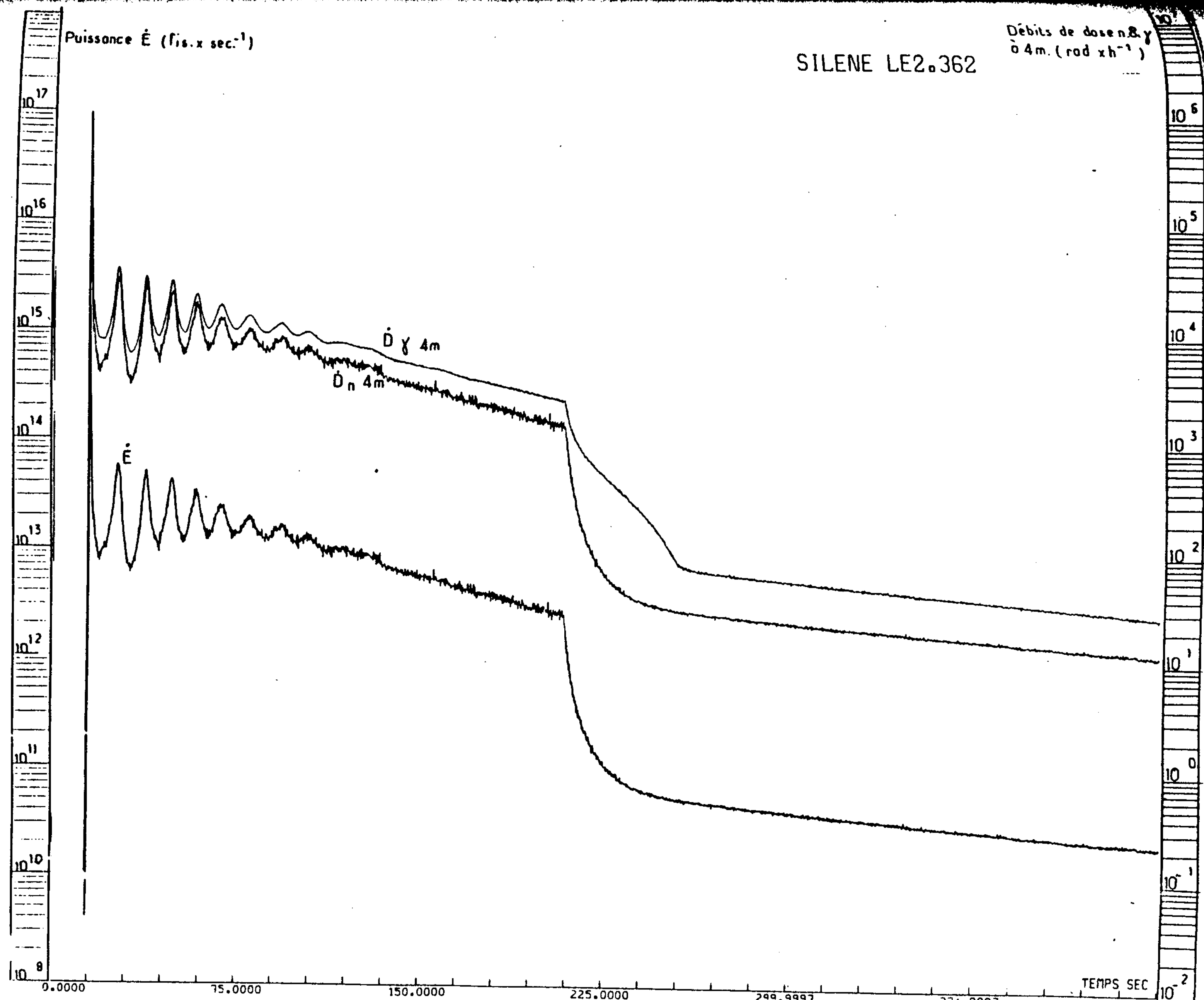
Puissance Ė (fis.s⁻¹)
Energie E (fissions)
SILENE LE1 362
Ė
E
Température (°C)
Température
TEMPS SEC
55.0000
57.5000
60.0000
62.5000
65.0000
67.5000
70.0000



SILENE LE1 362
Puissance Ė (fis.s-1)
Energie E (fissions)
Ė
E
Barre
Température
Déplacement barre (cm)
Température (°C)
TEMPS
55.0000
57.5000
60.0000
62.5000
65.0000
67.5000

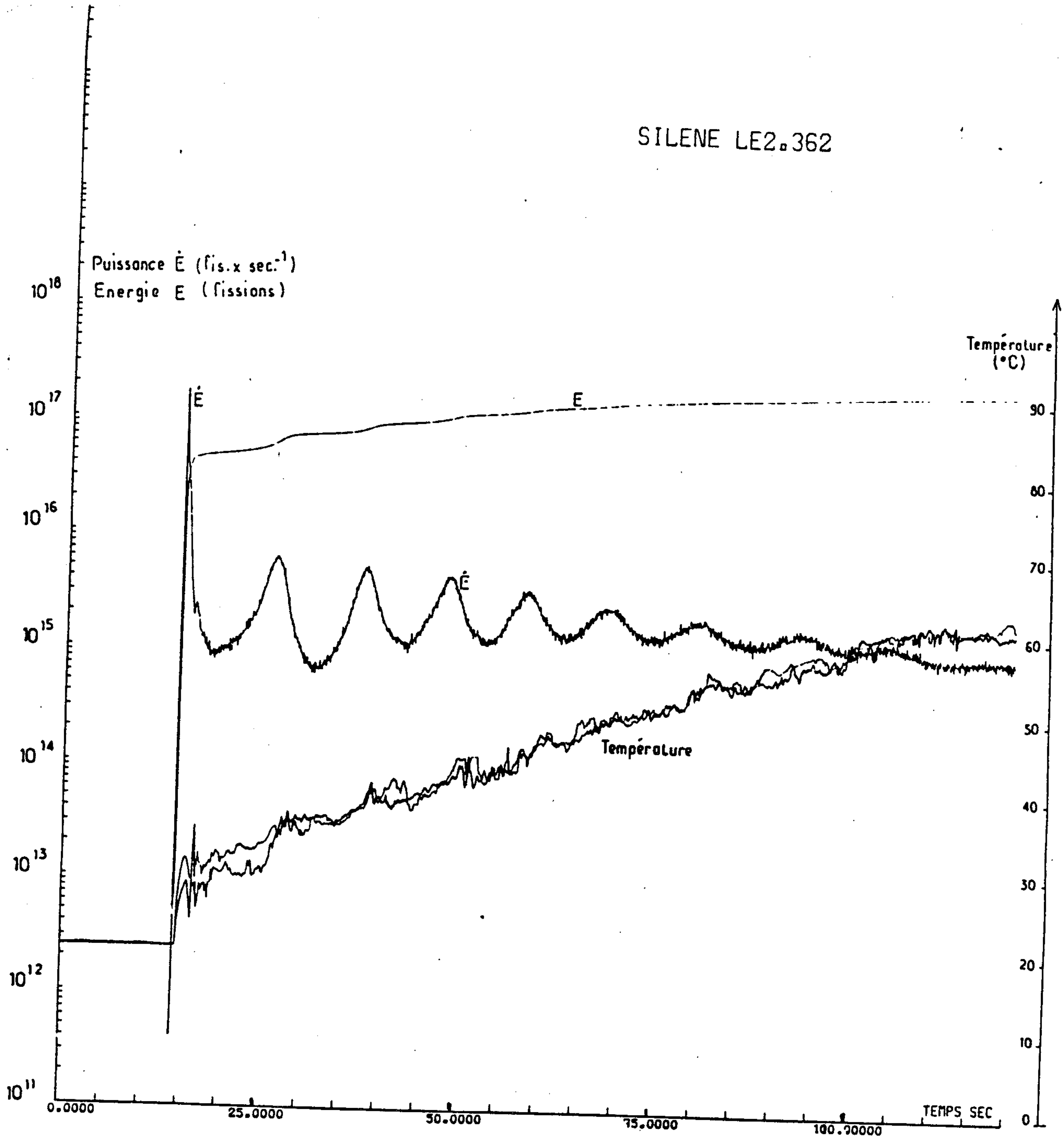
SILENE LE2.362



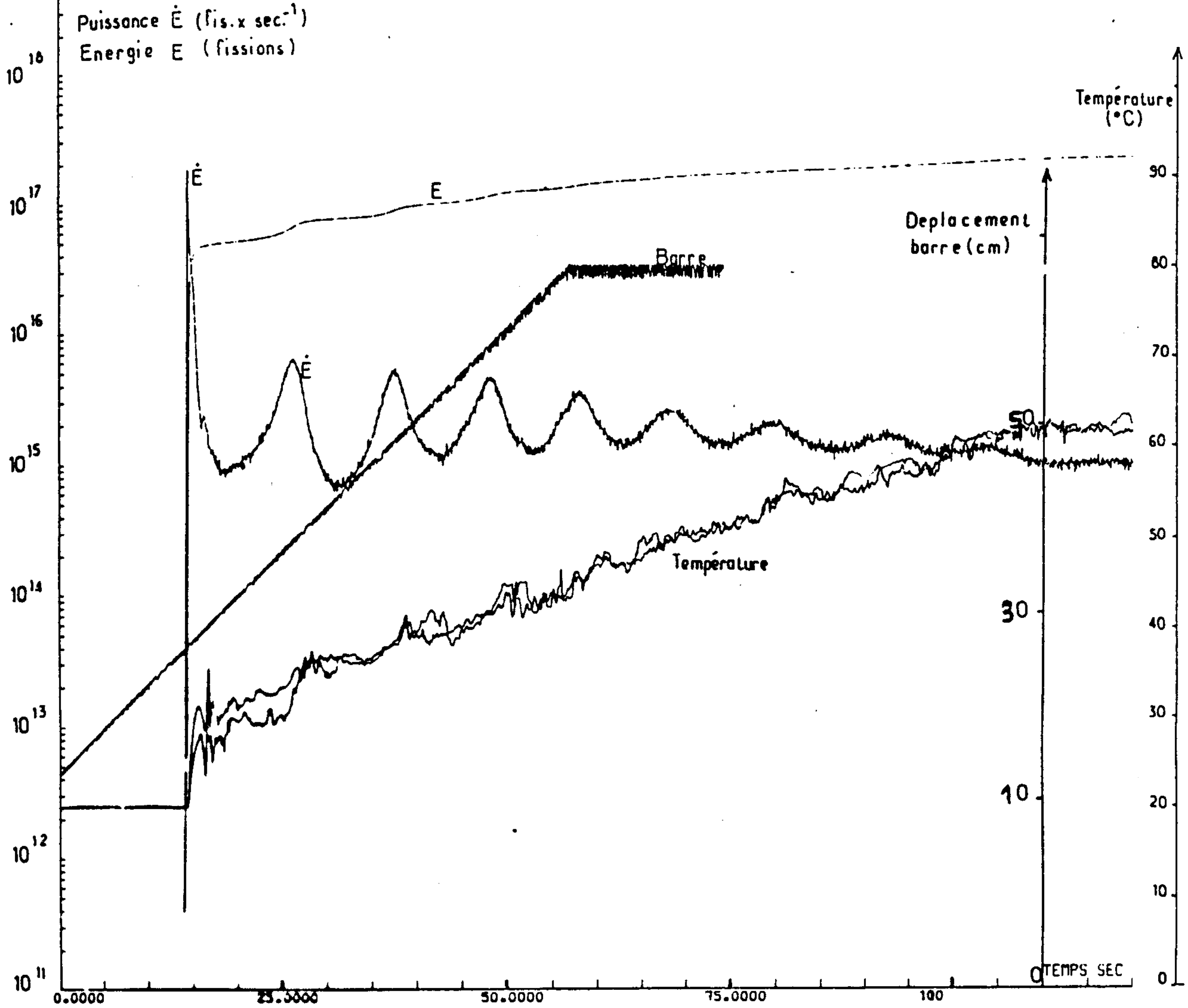


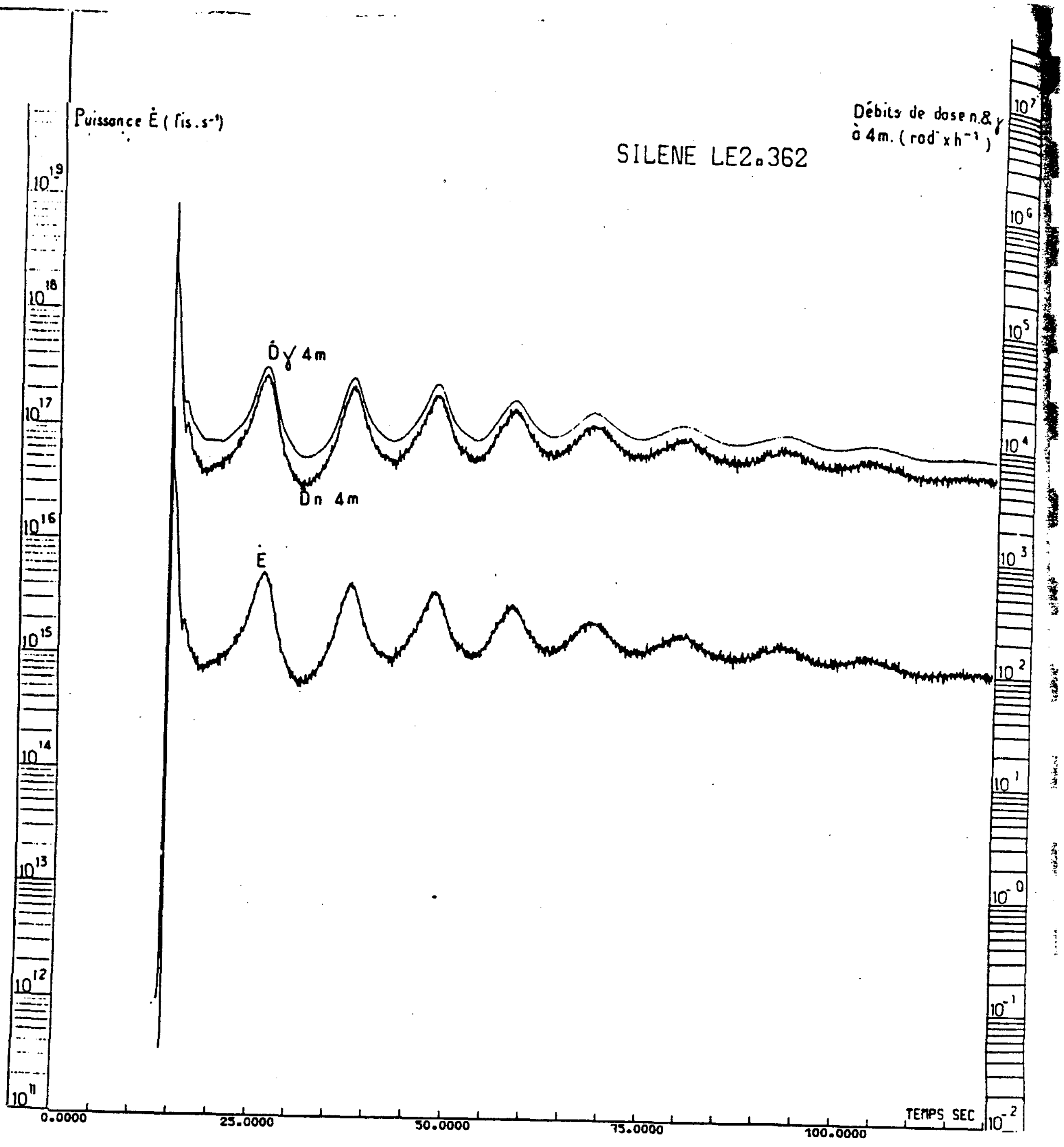
SILENE LE2.362
Puissance Ė (fis.x sec.⁻¹)
Débits de dose n & γ à 4m. (rad x h⁻¹)
Ḋ γ 4m
Ḋ n 4m
Ė
TEMPS SEC
0.0000
75.0000
150.0000
225.0000
299.9997
374.9997
449.9997

SILENE LE2.362



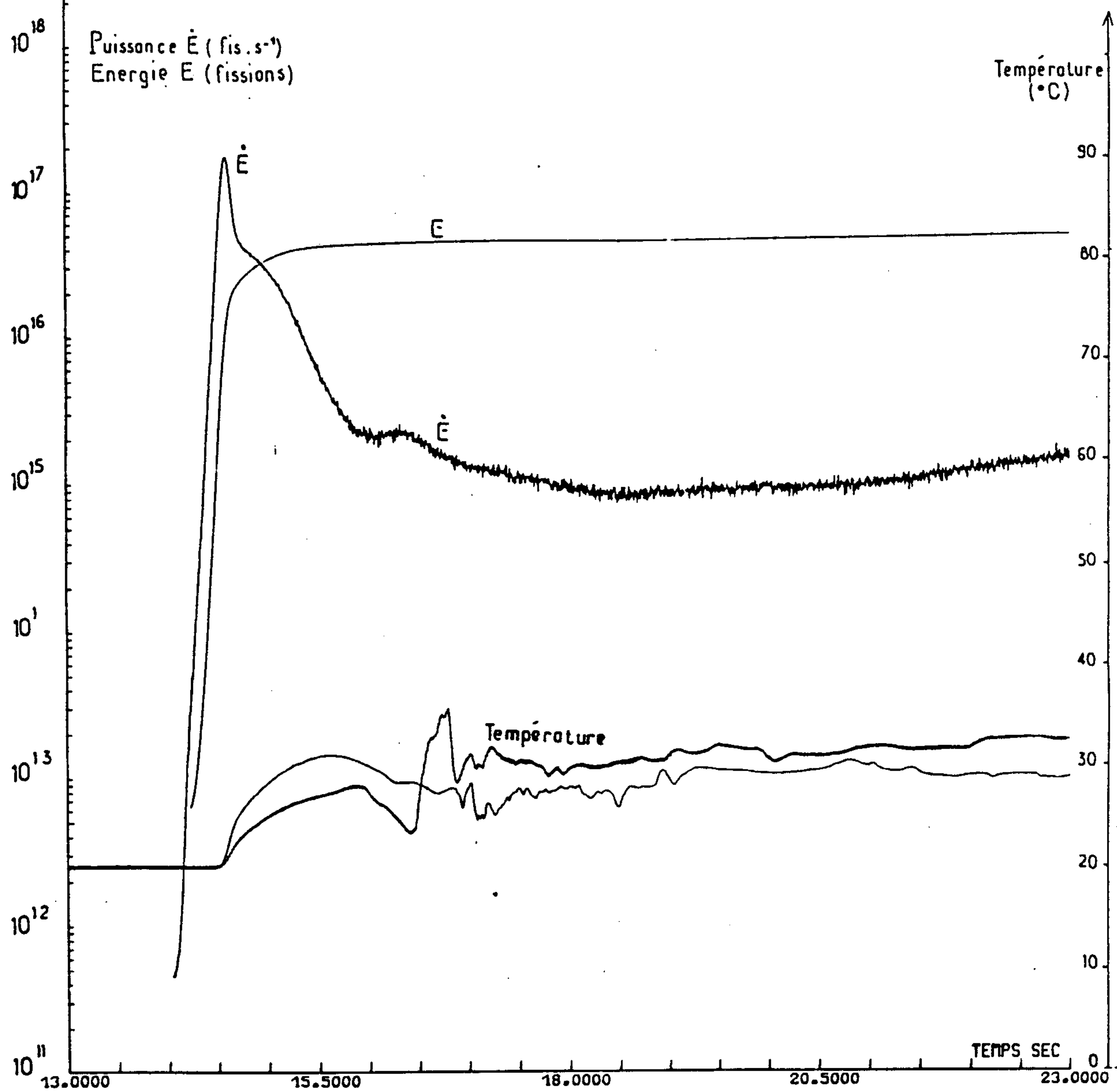
SILENE LE2.362



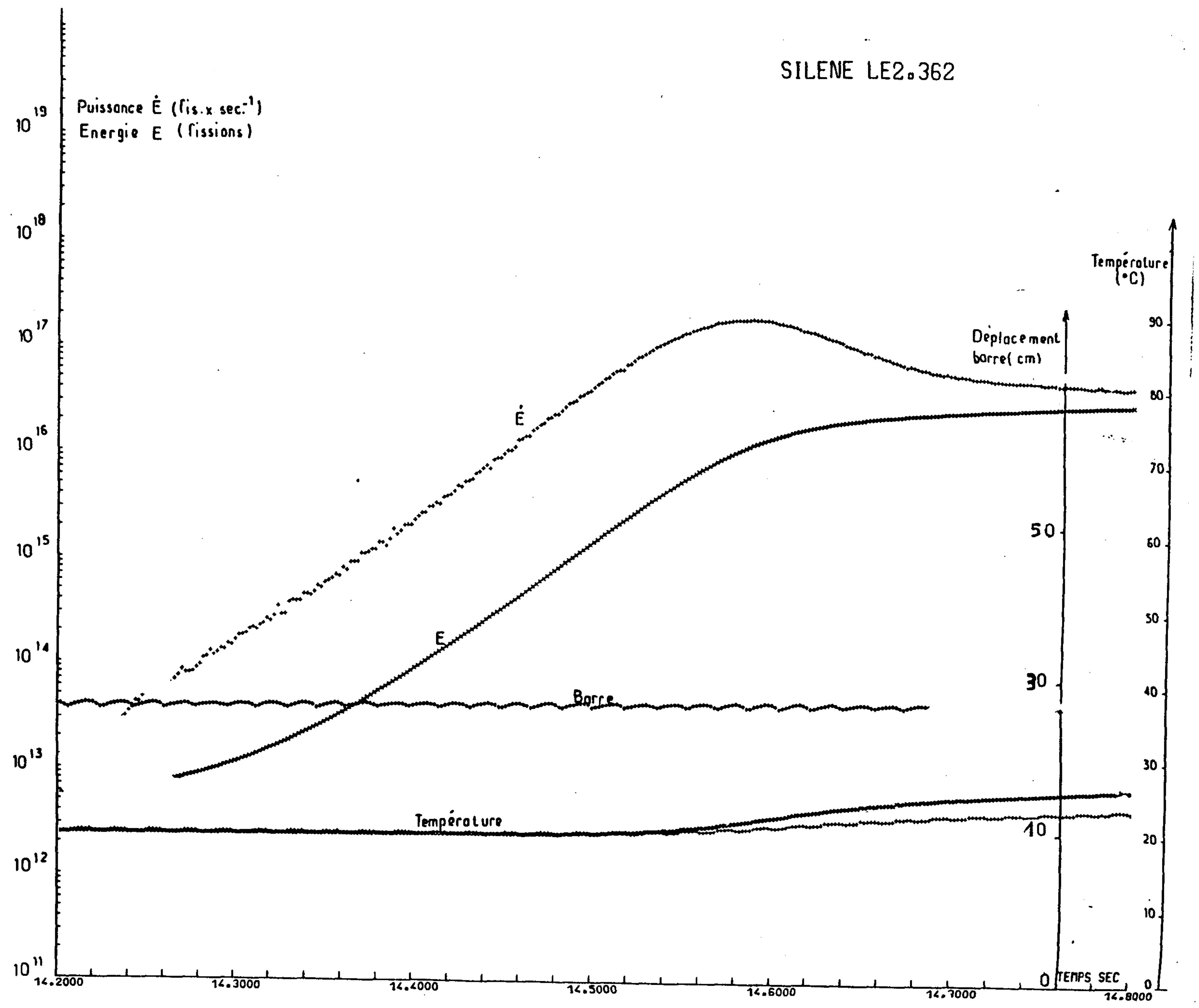


Puissance Ė (fis.s⁻¹)
SILENE LE2.362
Débits de dose n.& γ
à 4m. (rad x h⁻¹)
Ḋγ 4m
Ḋn 4m
Ė
TEMPS SEC
0.0000
25.0000
50.0000
75.0000
100.0000

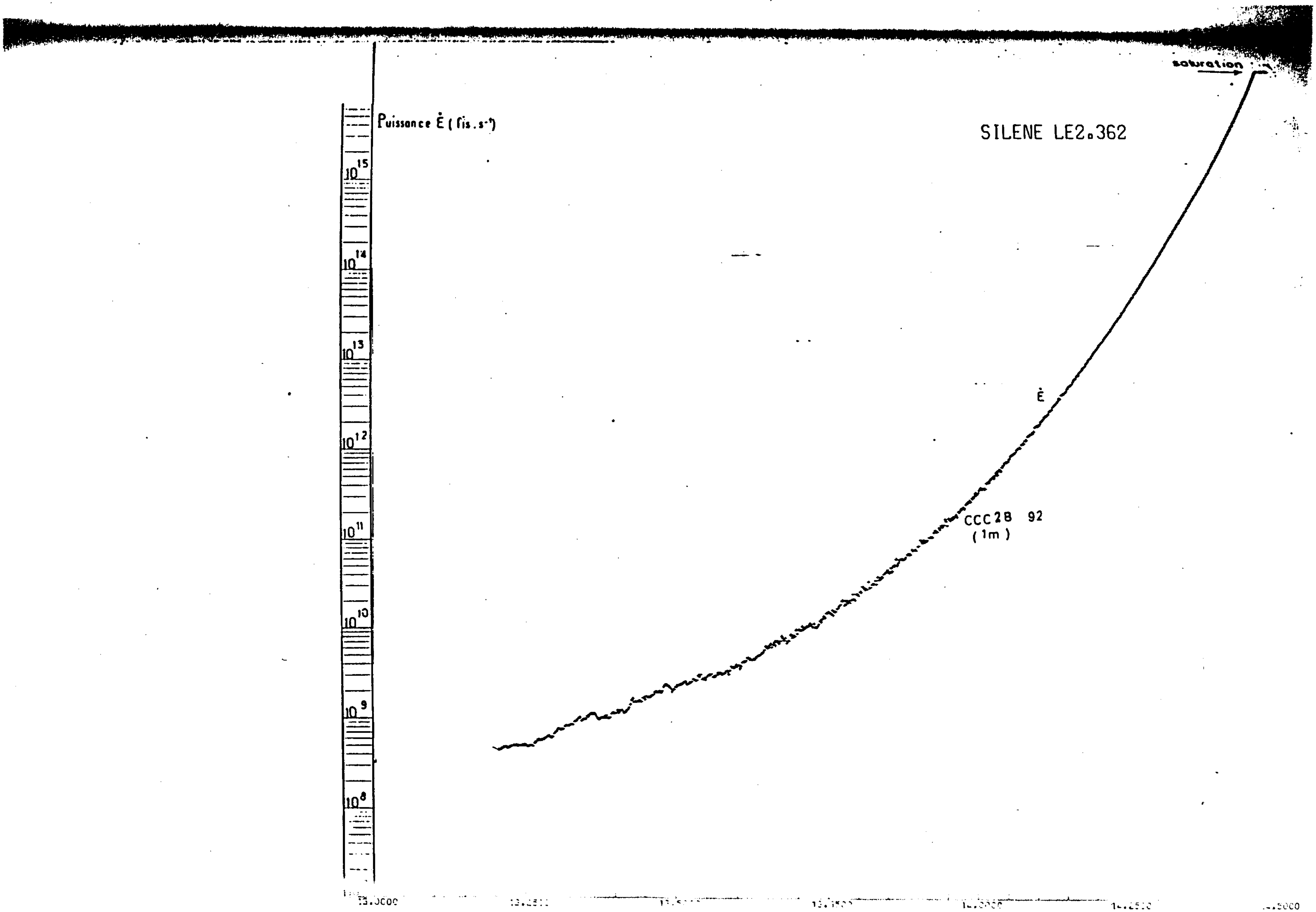
LE2.362



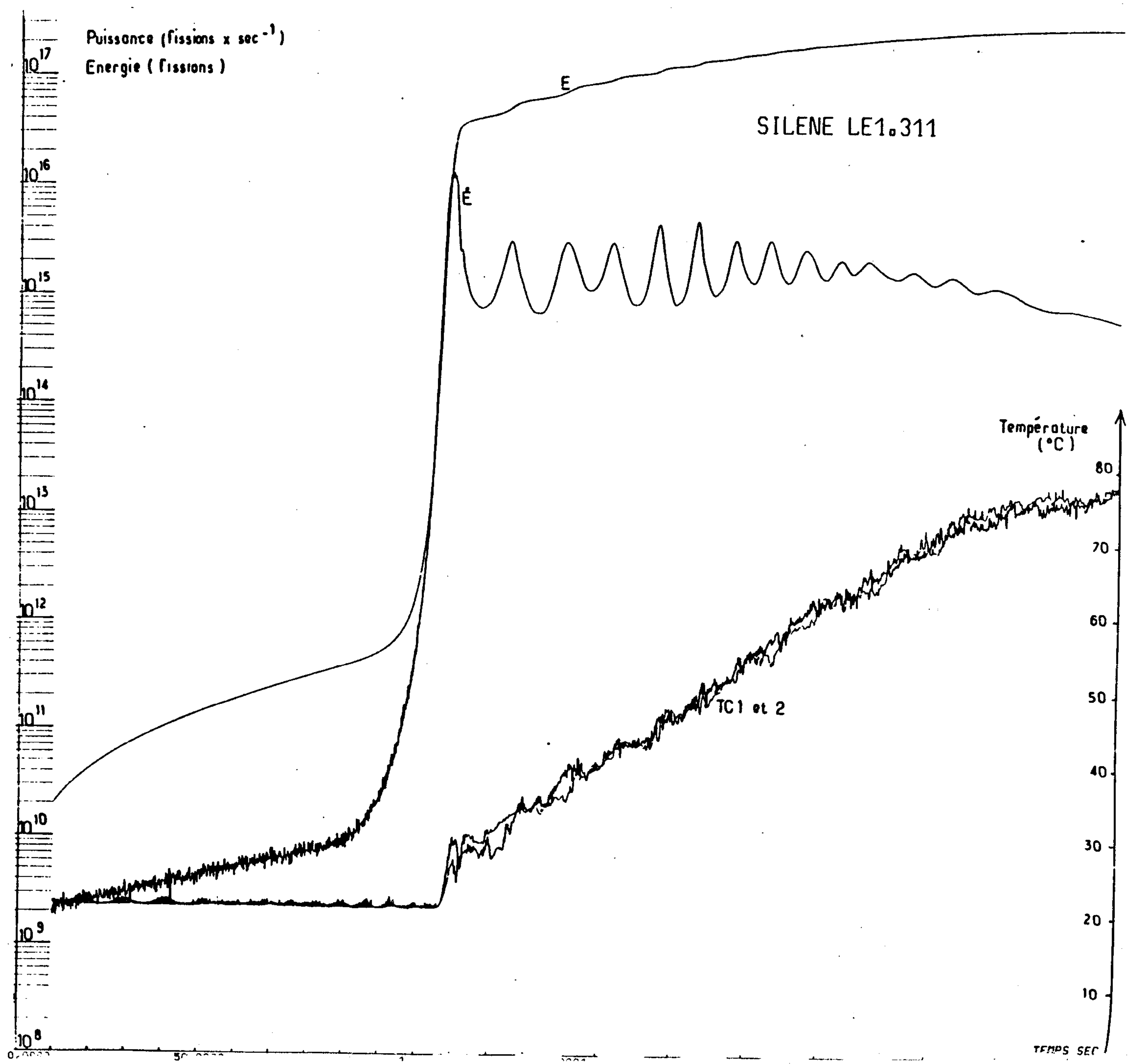
Puissance Ė (fis.s⁻¹)
Energie E (fissions)
Température (°C)
Ė
E
Ė
Température
TEMPS SEC
13.0000
15.5000
18.0000
20.5000
23.0000



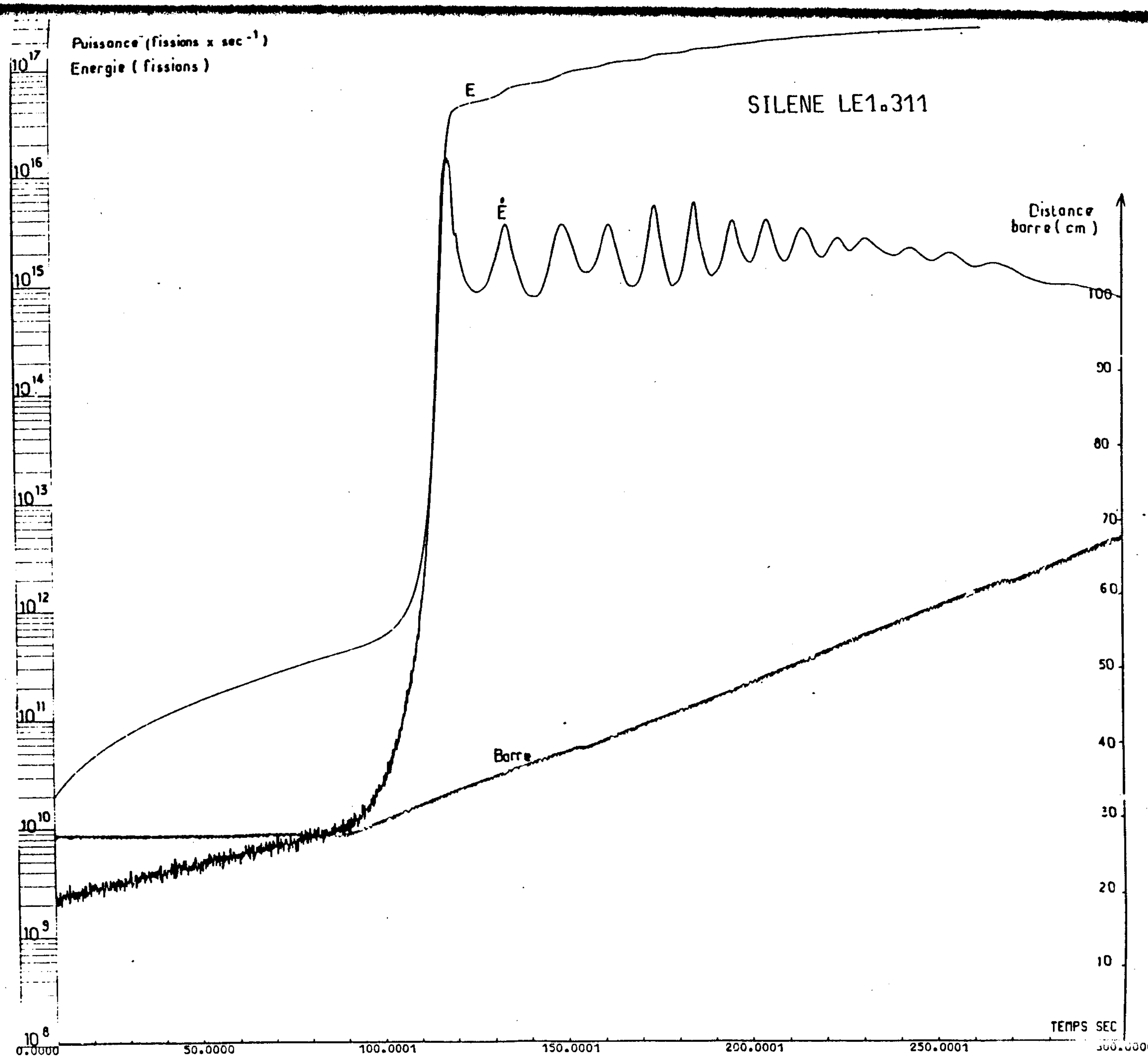
SILENE LE2.362
Puissance Ė (fis.x sec.$^{-1}$)
Energie E (fissions)
10 19
10 18
10 17
10 16
10 15
10 14
10 13
10 12
10 11
Ė
E
Barre
Température
Déplacement barre(cm)
50
30
10
0
Température (°C)
90
80
70
60
50
40
30
20
10
0
TEMPS SEC
14.2000
14.3000
14.4000
14.5000
14.6000
14.7000
14.8000



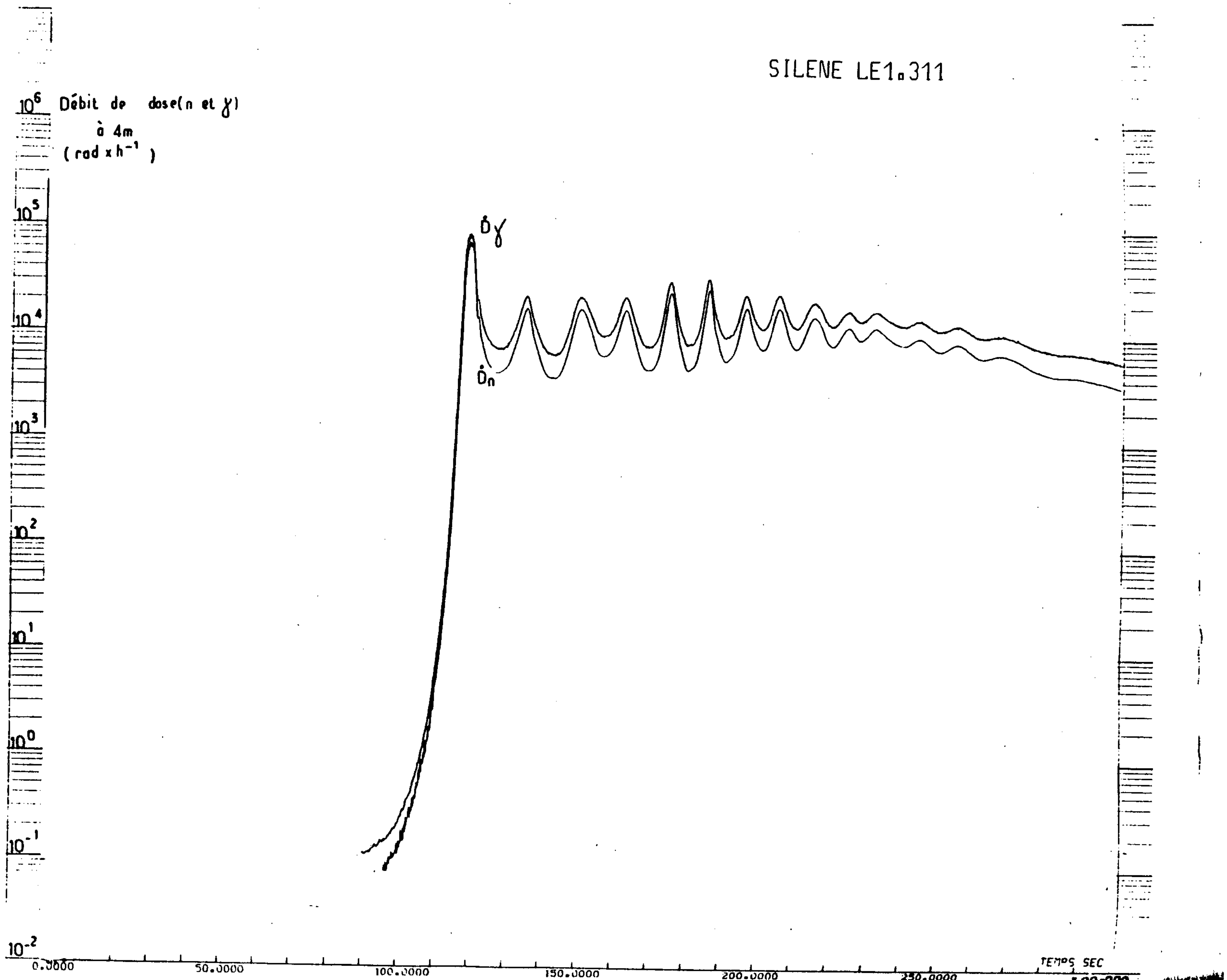
SILENE LE2.362
saturation
Puissance Ė (fis.s-1)
10^15
10^14
10^13
10^12
10^11
10^10
10^9
10^8
Ė
CCC 2B 92
(1m)
13.0000



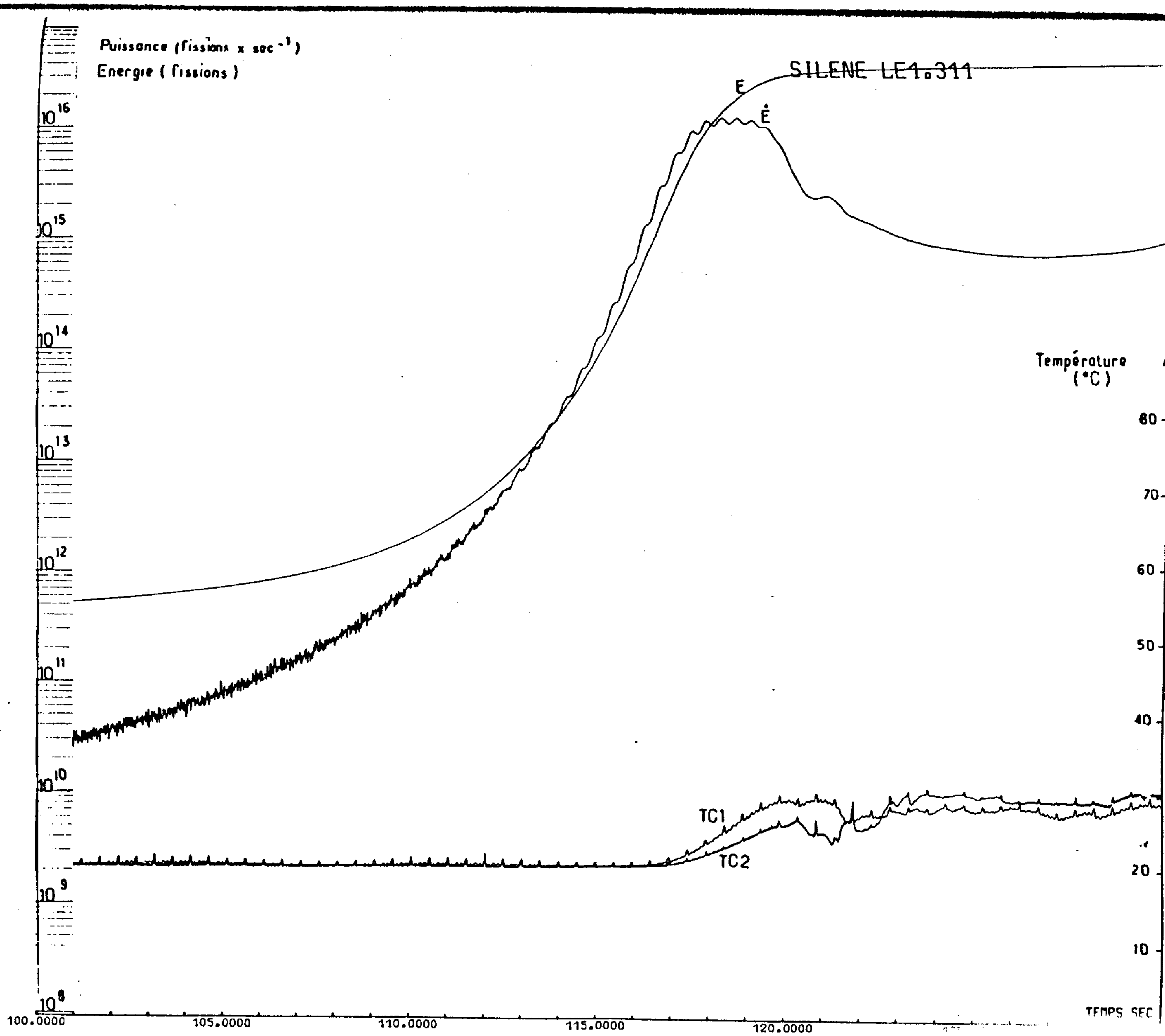
Puissance (fissions x sec⁻¹)
Energie (fissions)
SILENE LE1.311
E
Ė
Température (°C)
TC1 et 2
TEMPS SEC



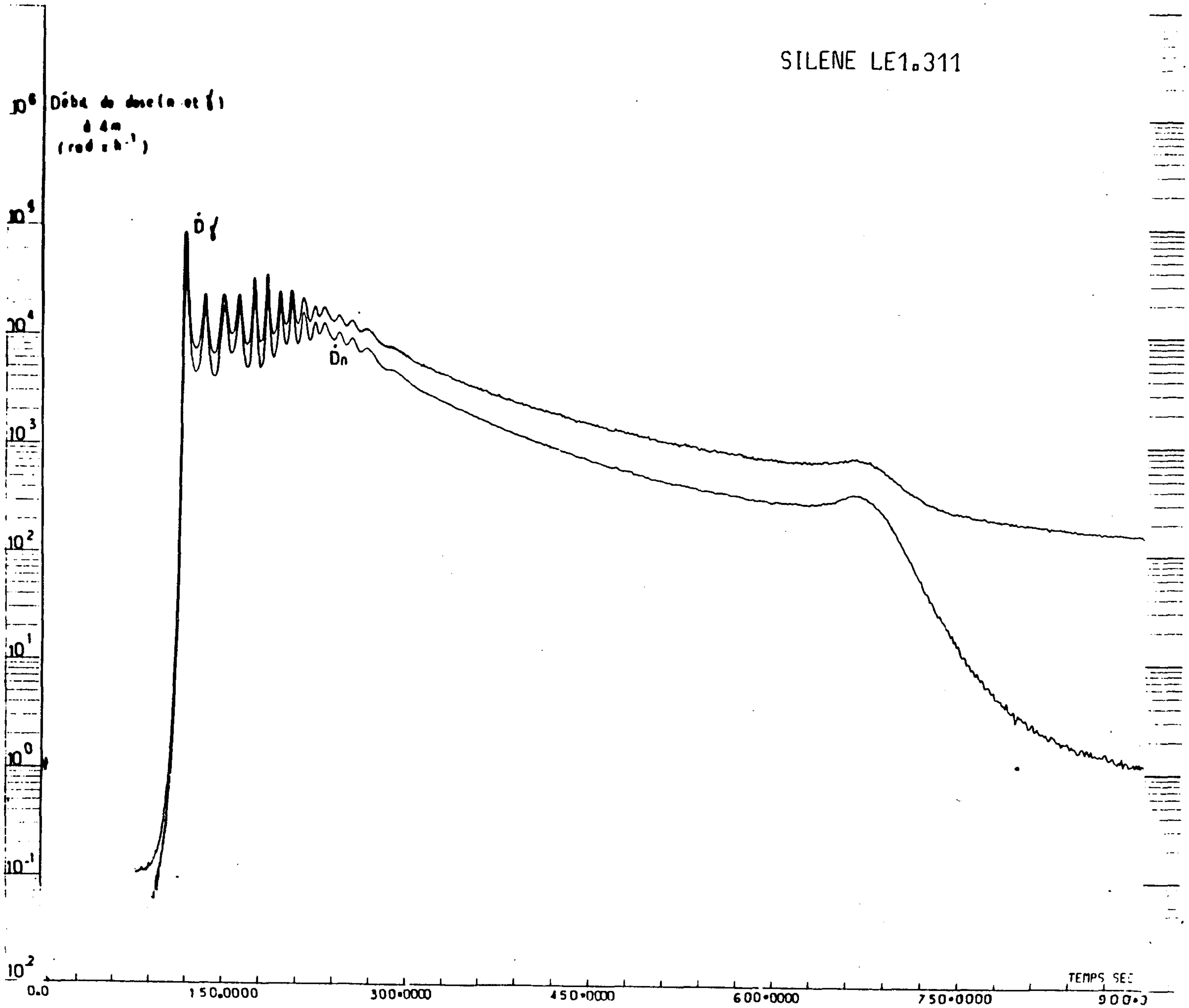
Puissance (fissions x sec⁻¹)
Energie (fissions)
SILENE LE1.311
E
Ė
Distance barre (cm)
Barre
TEMPS SEC
0.0000
50.0000
100.0001
150.0001
200.0001
250.0001
300.0000



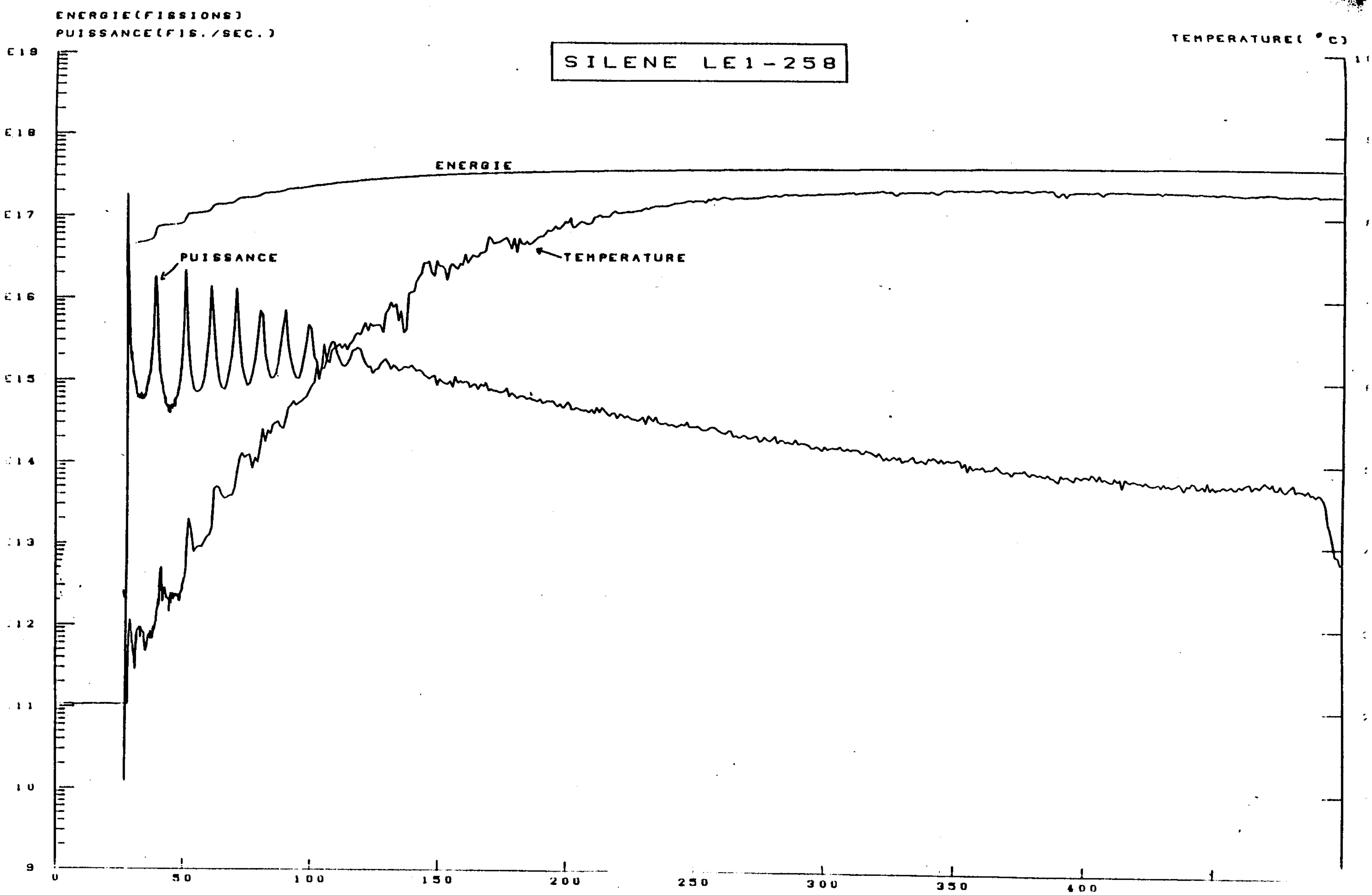
Débits de dose neutron et gamma à 4 m.



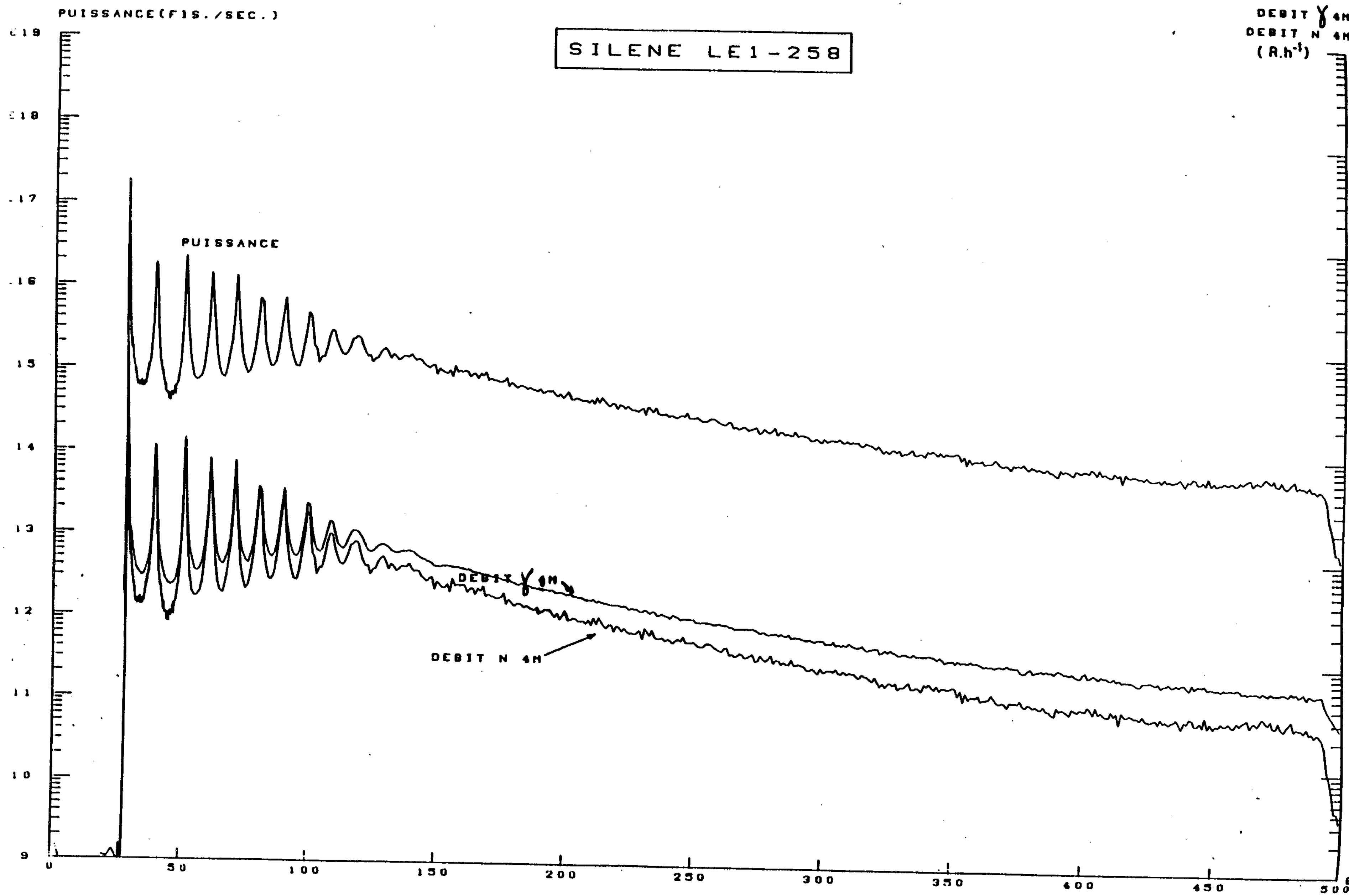
Puissance (fissions x sec⁻¹)
Energie (fissions)
SILENE LE1.311
E
Ė
Température (°C)
TC1
TC2
TEMPS SEC
100.0000
105.0000
110.0000
115.0000
120.0000
80
70
60
50
40
20
10



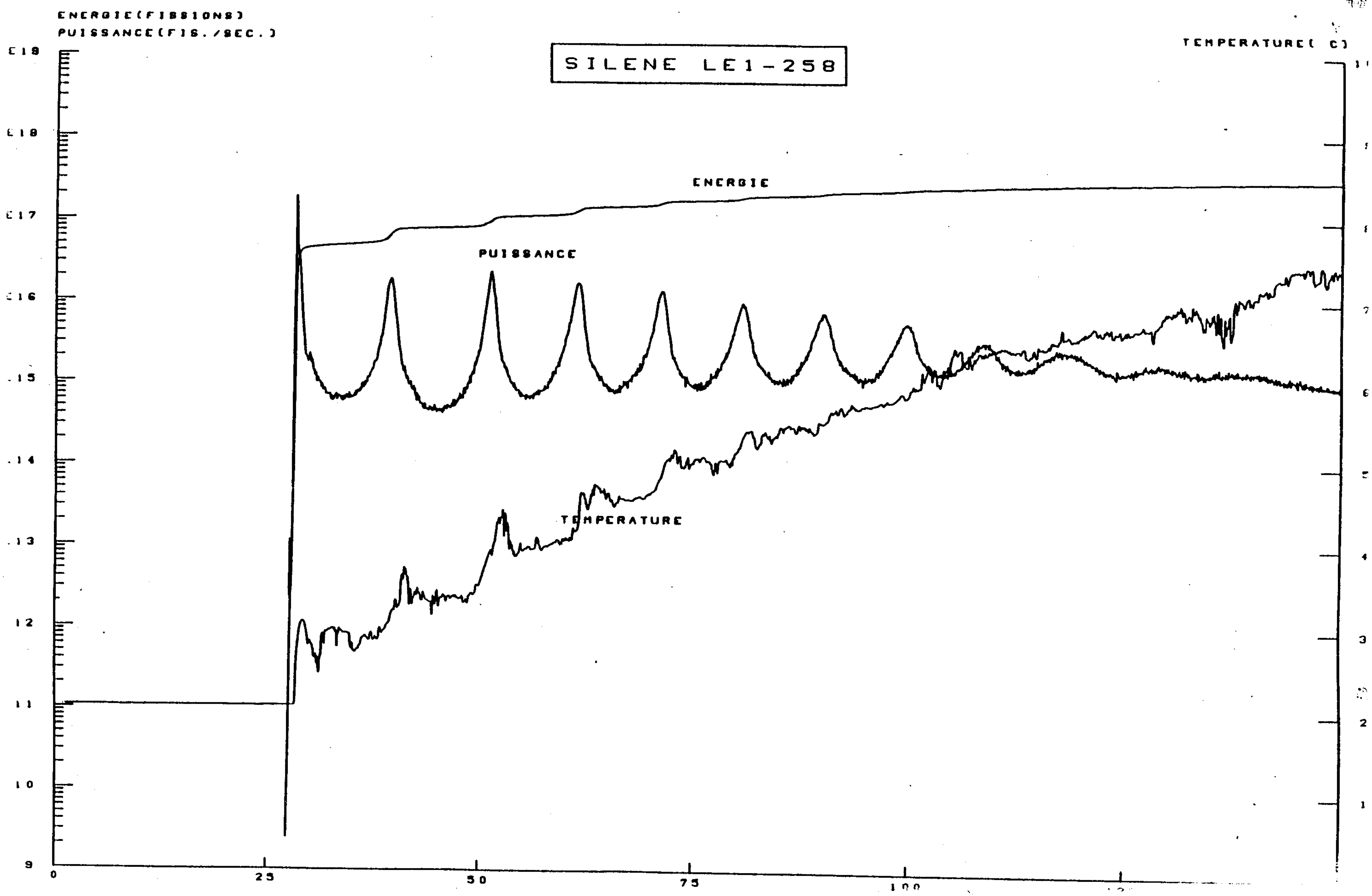
Débits de dose neutron et gamma à 4 m.



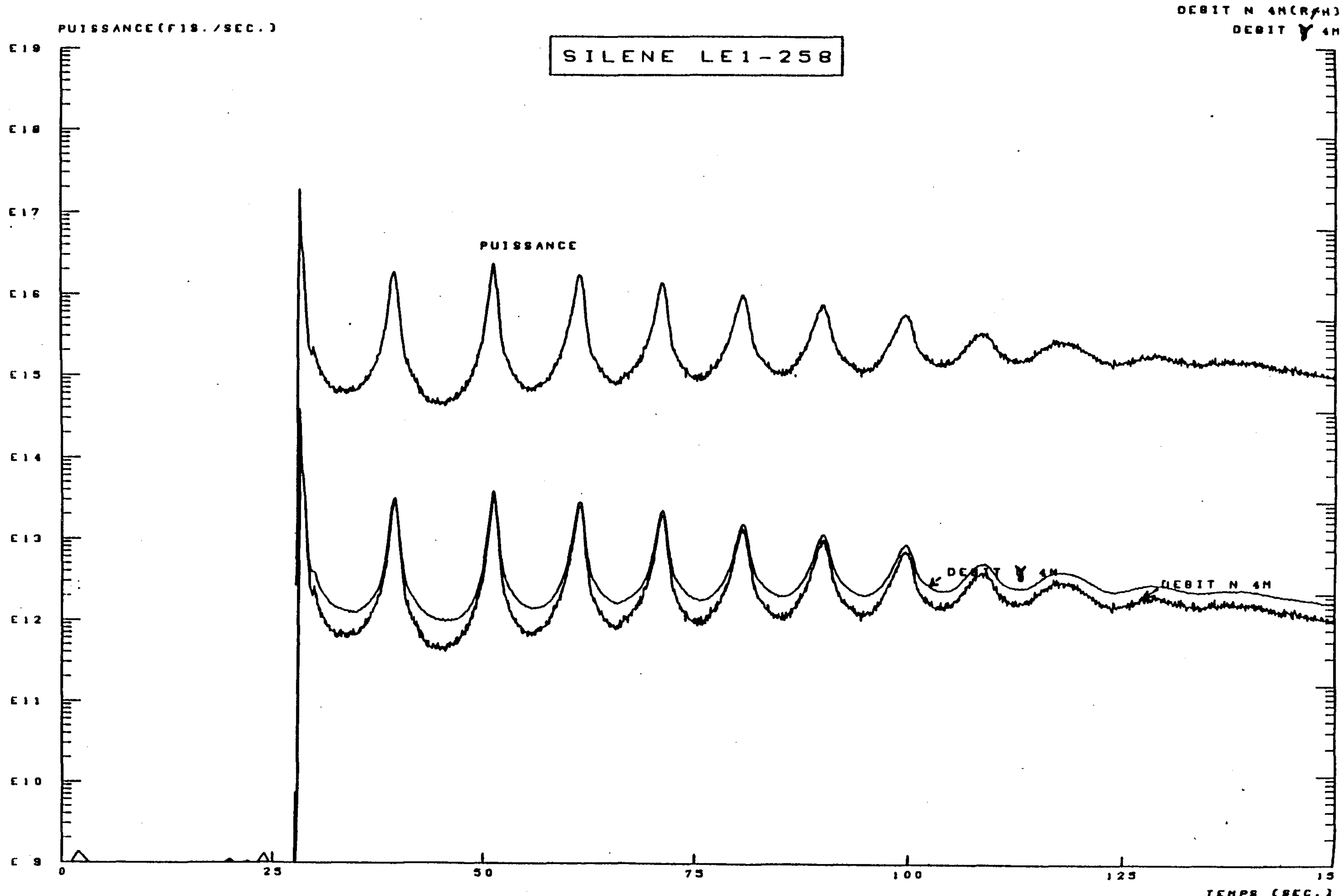
SILENE- EVOLUTION DE LA PUISSANCE , DE L'ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



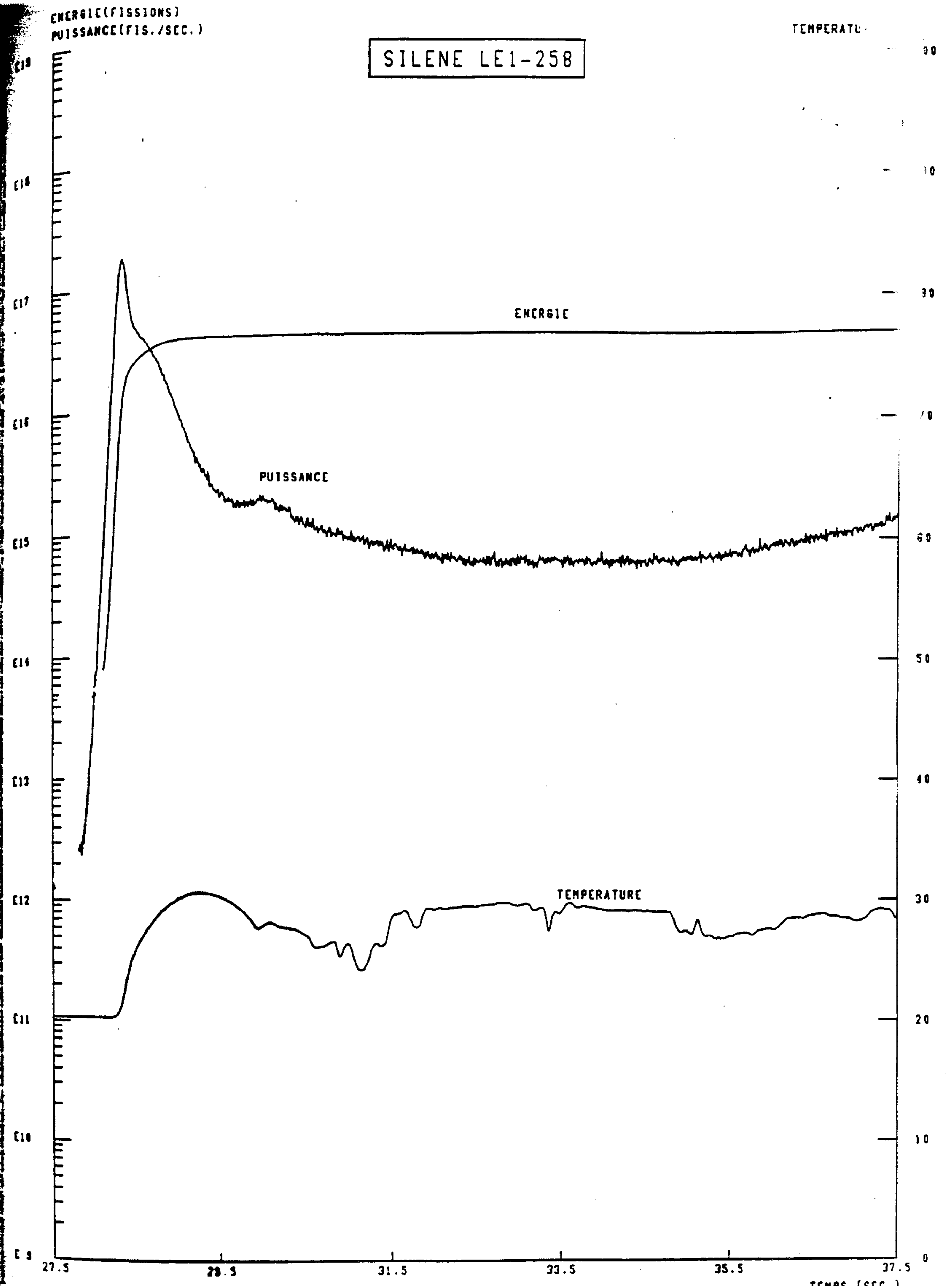
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR
ET DEBITS DE DOSES N ET γ A 4M DU REACTEUR



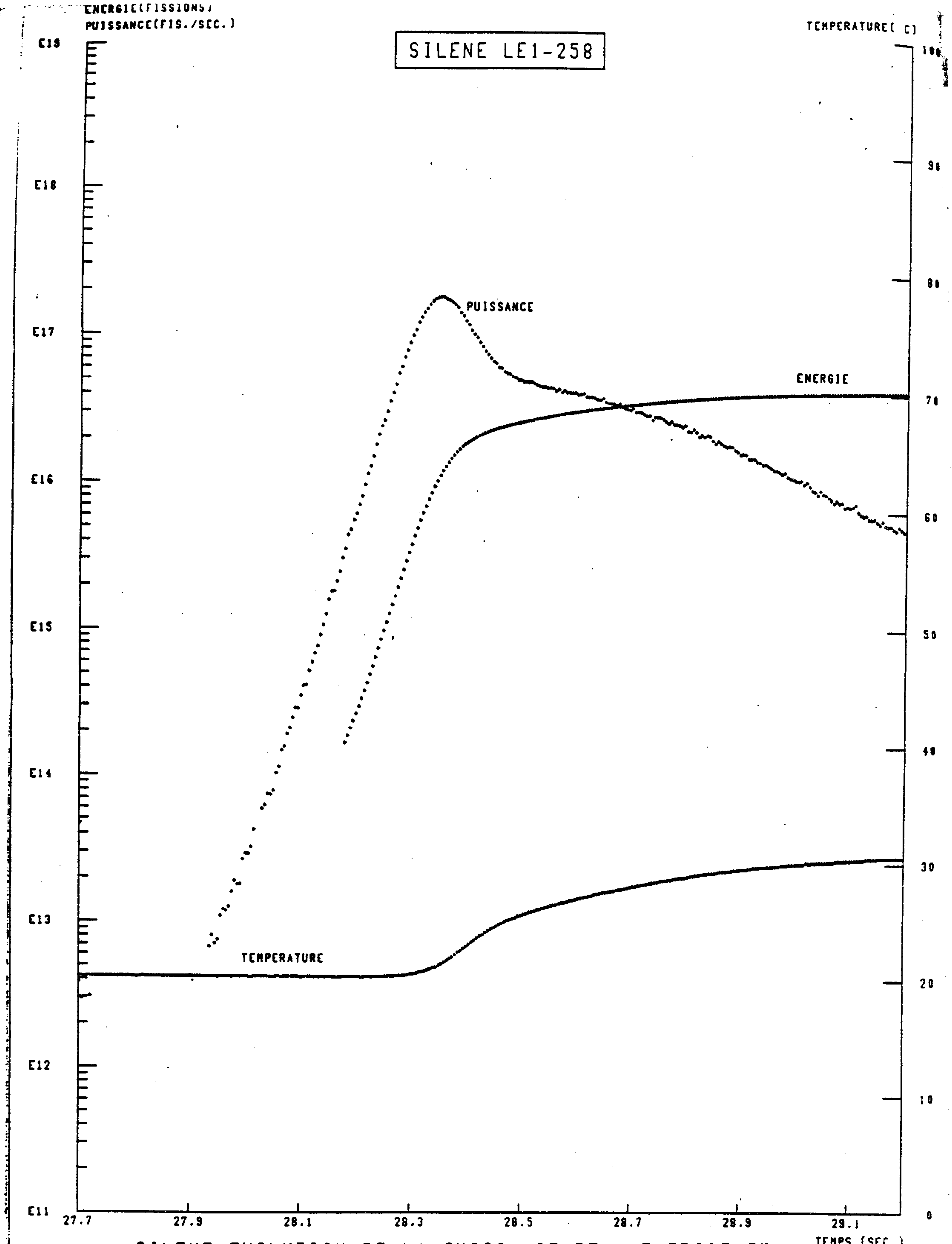
SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



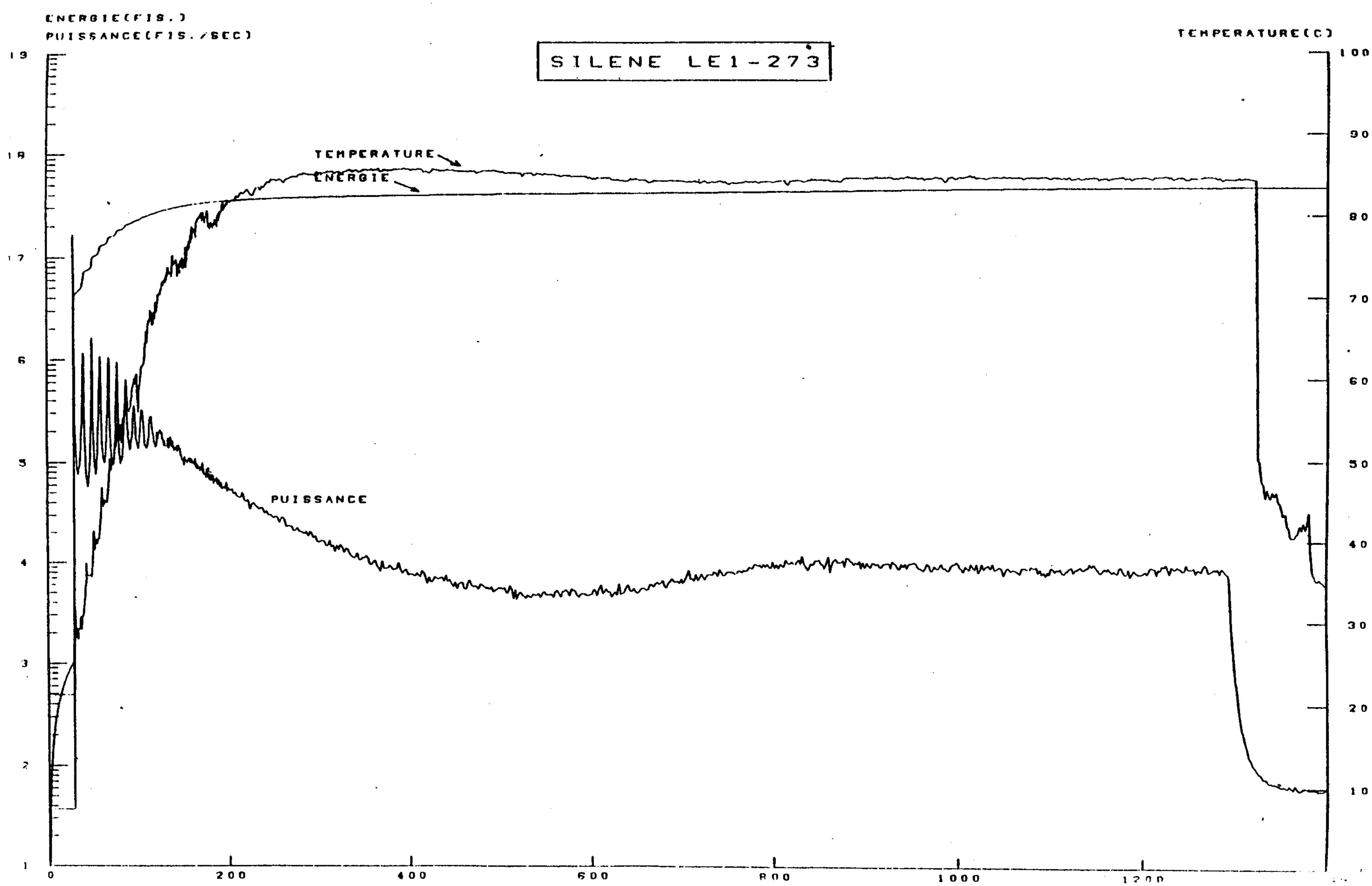
SILENE-EVOLUTION DE LA PUISSANCE AU SEIN DU REACTEUR



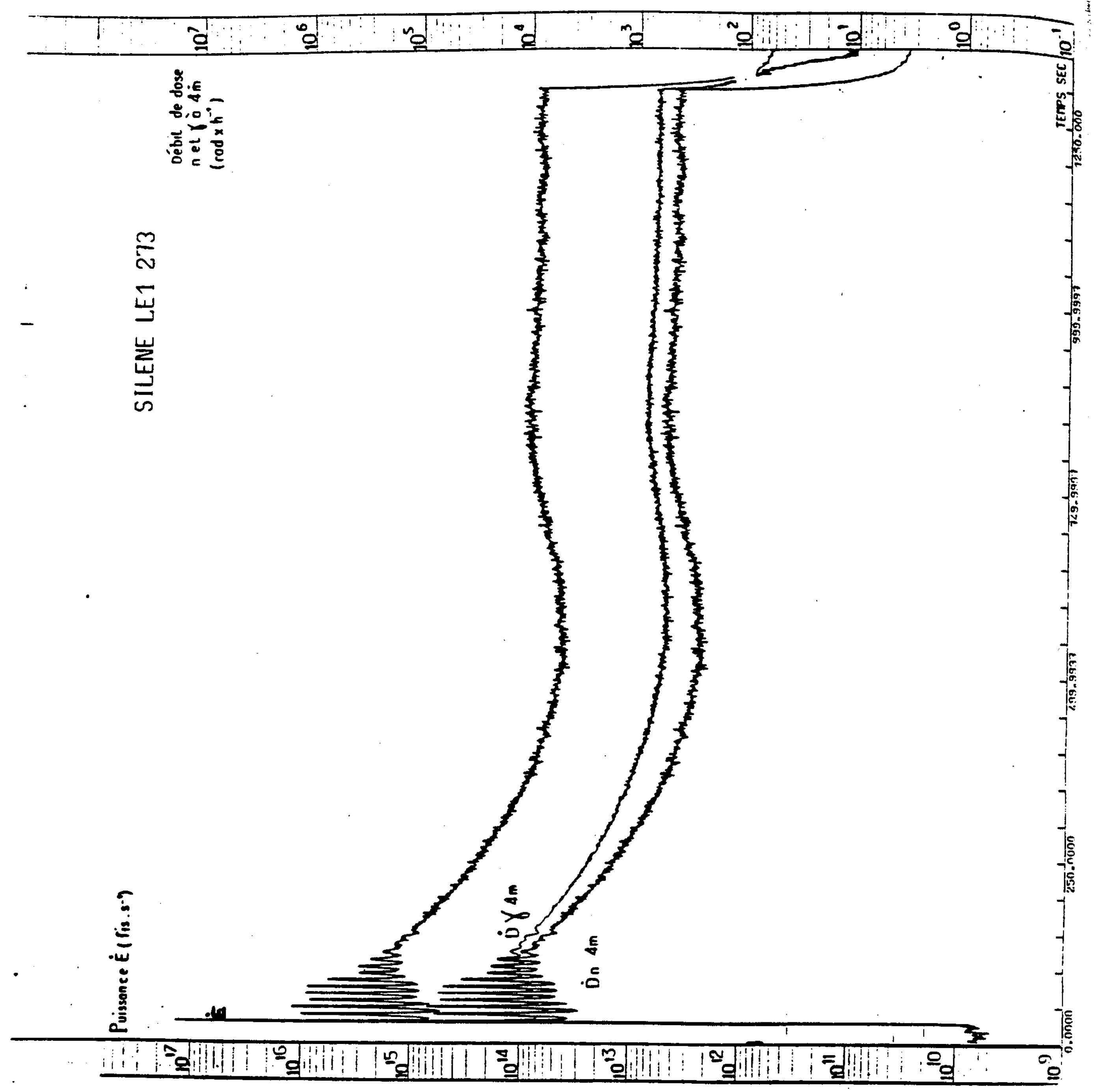
SILENE-EVOLUTION DE LA PUISSANCE,DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR(1ER PIC)



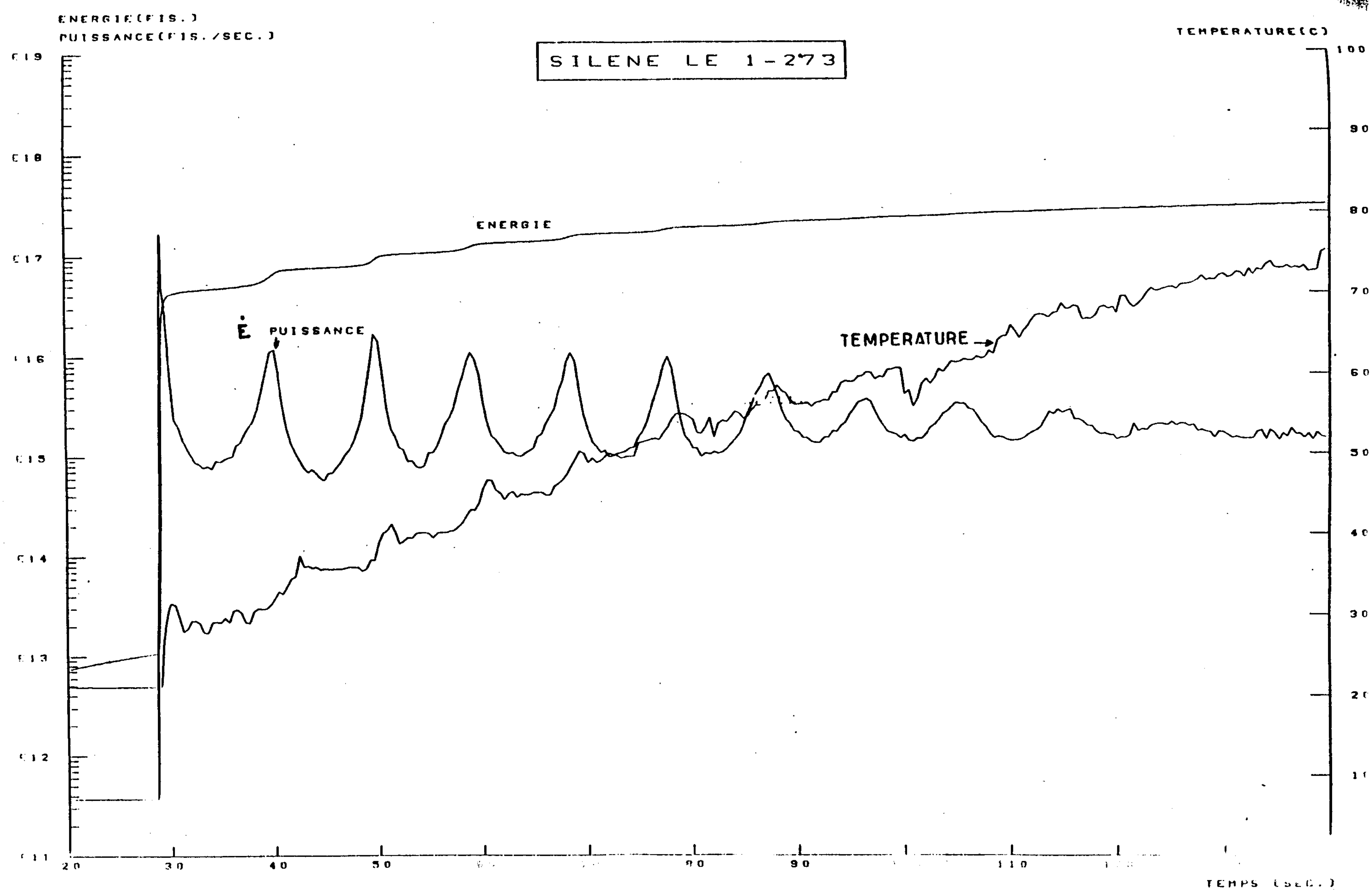
SILENE-EVOLUTION DE LA PUISSANCE,DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR(1ER PIC DETAIL)



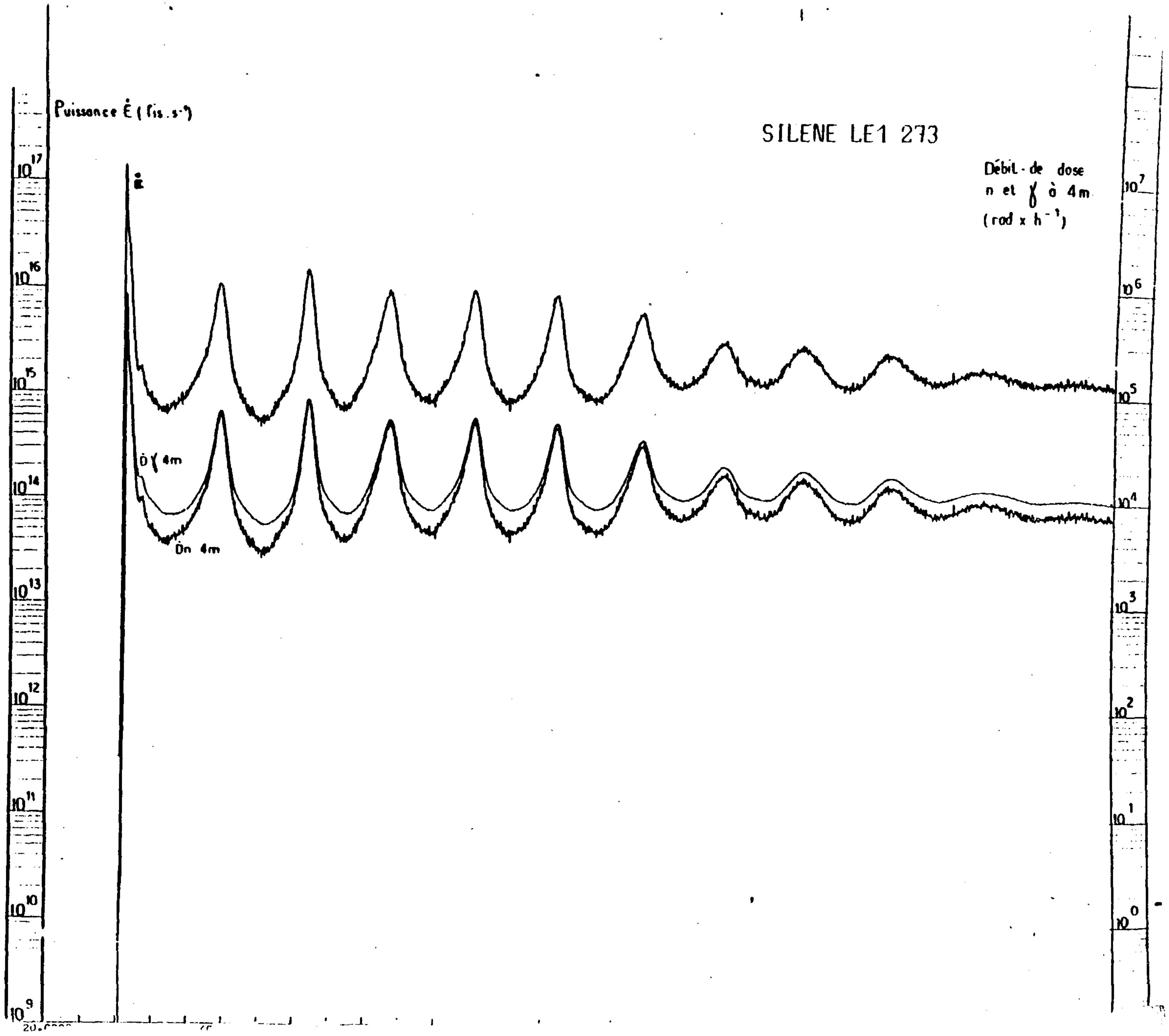
SILENE-EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



SILENE - Puissance, débits de dose neutrons et gamma à 4 m du réacteur.



SILENE EVOLUTION DE LA PUISSANCE, DE L ENERGIE ET DE LA TEMPERATURE AU SEIN DU REACTEUR



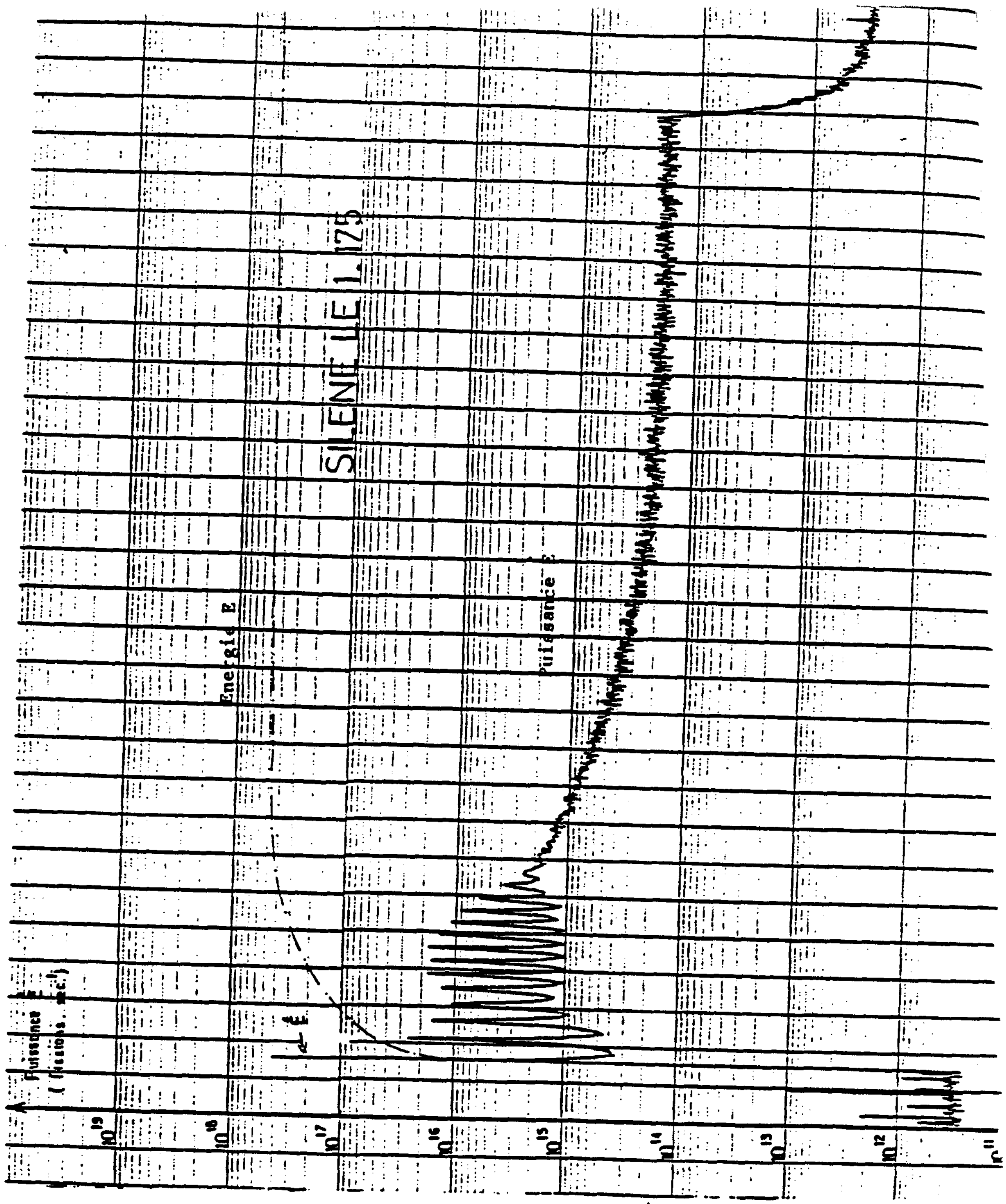
SILENE - Puissance, débits de dose neutrons et gamma à 4 m du réacteur.

SILENE

"BOILING" TYPE EXPERIMENTS

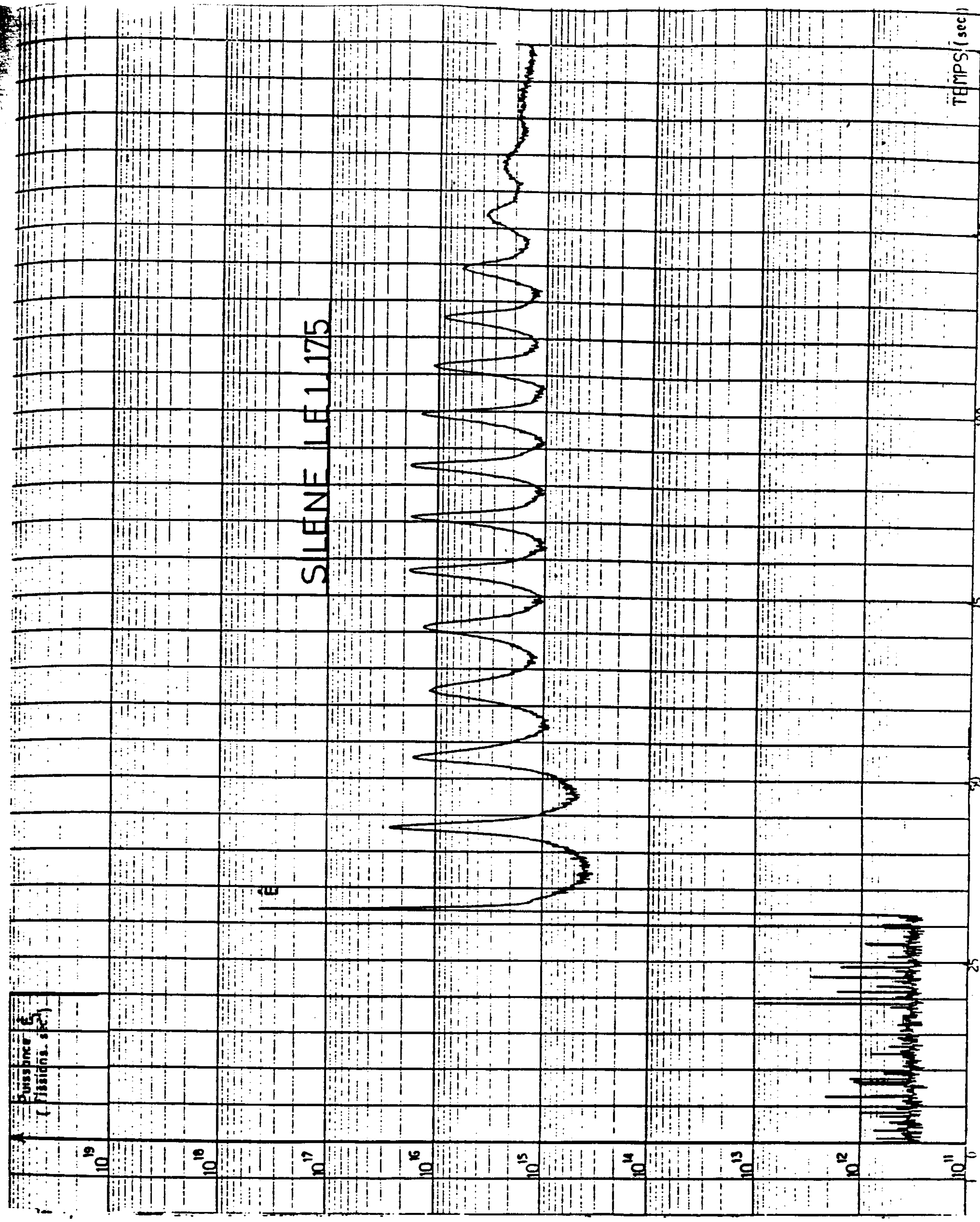
NUMBER	$C_{u\,g/l}$	$H_{c\,cm}$	ΔH_{mm}	$H_{f\,cm}$	$V_{f\,l}$	1st PEAK								
						$T_{2\,s}$	$\omega_{s^{-1}}$	$\dot{E}_{fissions\ s^{-1}}$	$\hat{E}_{fissions}$	$E_{p_1\,fissions}$	$E_{p_2\,fissions}$	ΔP_{bar}	$\Delta k_{1\,PCM}$	$\Delta k_{1\,\$}$
LE1-175	71.4	36.79	90	45.79	44.41	0.015	46	$4.2\ 10^{17}$	$1.7\ 10^{17}$	$4.2\ 10^{16}$	$4.6\ 10^{16}$		960	1.21
LE1-176	69.8	38.07	114.9	49.56	48.07	0.016	43	$4.5\ 10^{17}$	$1.8\ 10^{16}$	$3.7\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE2-176	69.8	38.07	139.9	52.06	50.49	0.018	38	$4.1\ 10^{17}$	$1.7\ 10^{16}$	$3.7\ 10^{16}$	$5.6\ 10^{16}$		930	1.17
LE2-343	70.6	37.1	140	51.1	49.57	0.016	42.5	$3.8\ 10^{17}$	$1.6\ 10^{16}$	$3.2\ 10^{16}$	$5.1\ 10^{16}$		950	1.20
LE1-281	70.9	37.42	170	54.42	52.79	0.017	41	$4.2\ 10^{17}$	$1.7\ 10^{16}$	$3.8\ 10^{16}$	$5.4\ 10^{16}$		940	1.18

NUMBER	TEMPERATURE		TOTAL REACTIVITY		DURATION	$N_{f\,fissions}$	SOURCE	CATEGORY
	$\Theta_{i\,°C}$	$\Delta\Theta_{°C\,max}$	$\Delta k_{p\,pcm}$	$\Delta k_{p\,\$}$				
LE1-175	19.6		4000	5.0	540	$5.4\ 10^{17}$	OUI	
LE1-176	18.8		4100	5.2	720	$6.9\ 10^{17}$	OUI	5.6
LE2-176	18.8		4800	6.0	900	$7.4\ 10^{17}$	OUI	5.6
LE2-343	22.4		5100	6.4	700	$8.7\ 10^{17}$	OUI	5.6
LE1-281	21		5700	7.2	600	$8.6\ 10^{17}$	OUI	5.6



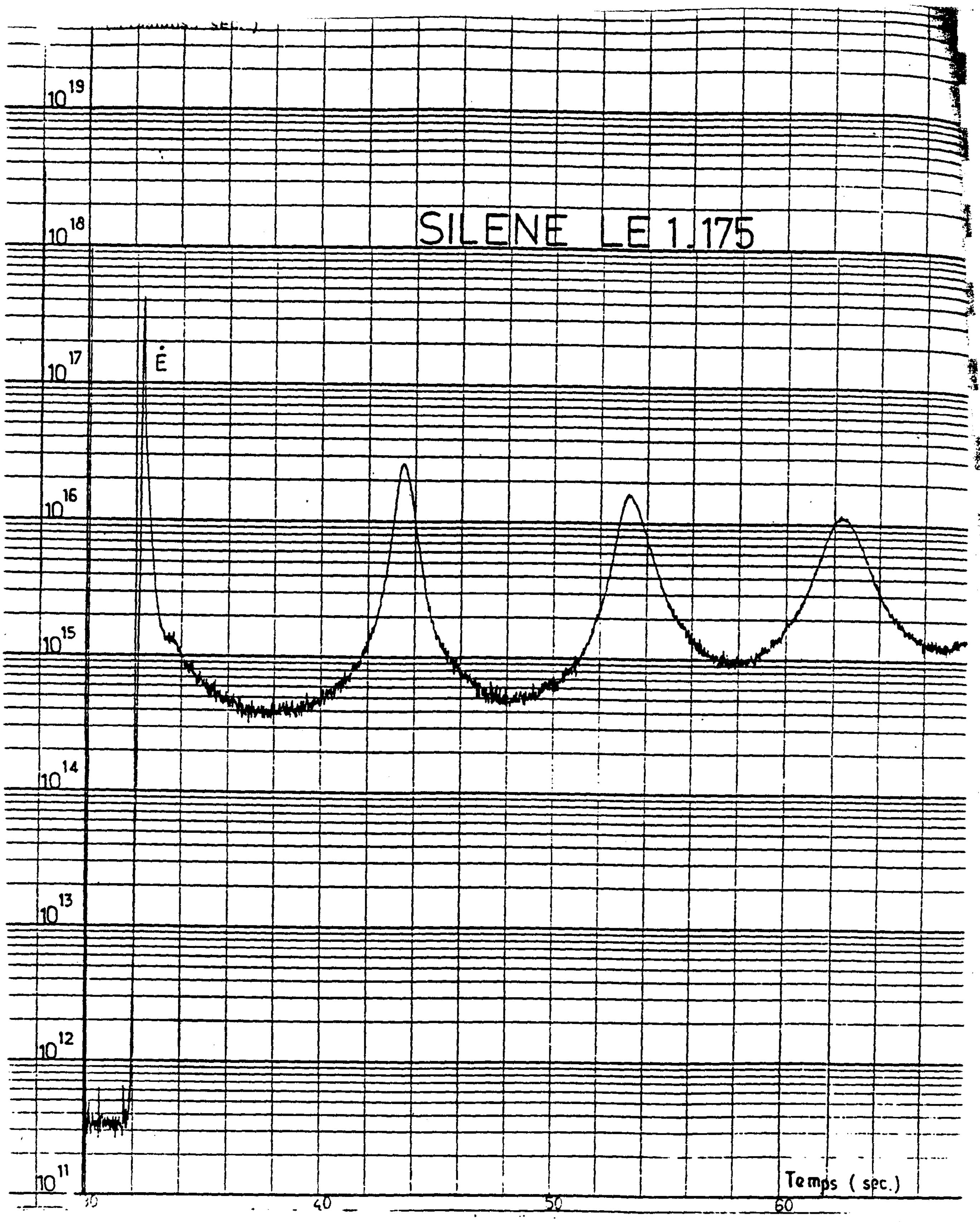
SILENE

Fig: 1 _Expérience du type " Ebullition"
Evolution de la puissance
(toute l'expérience)



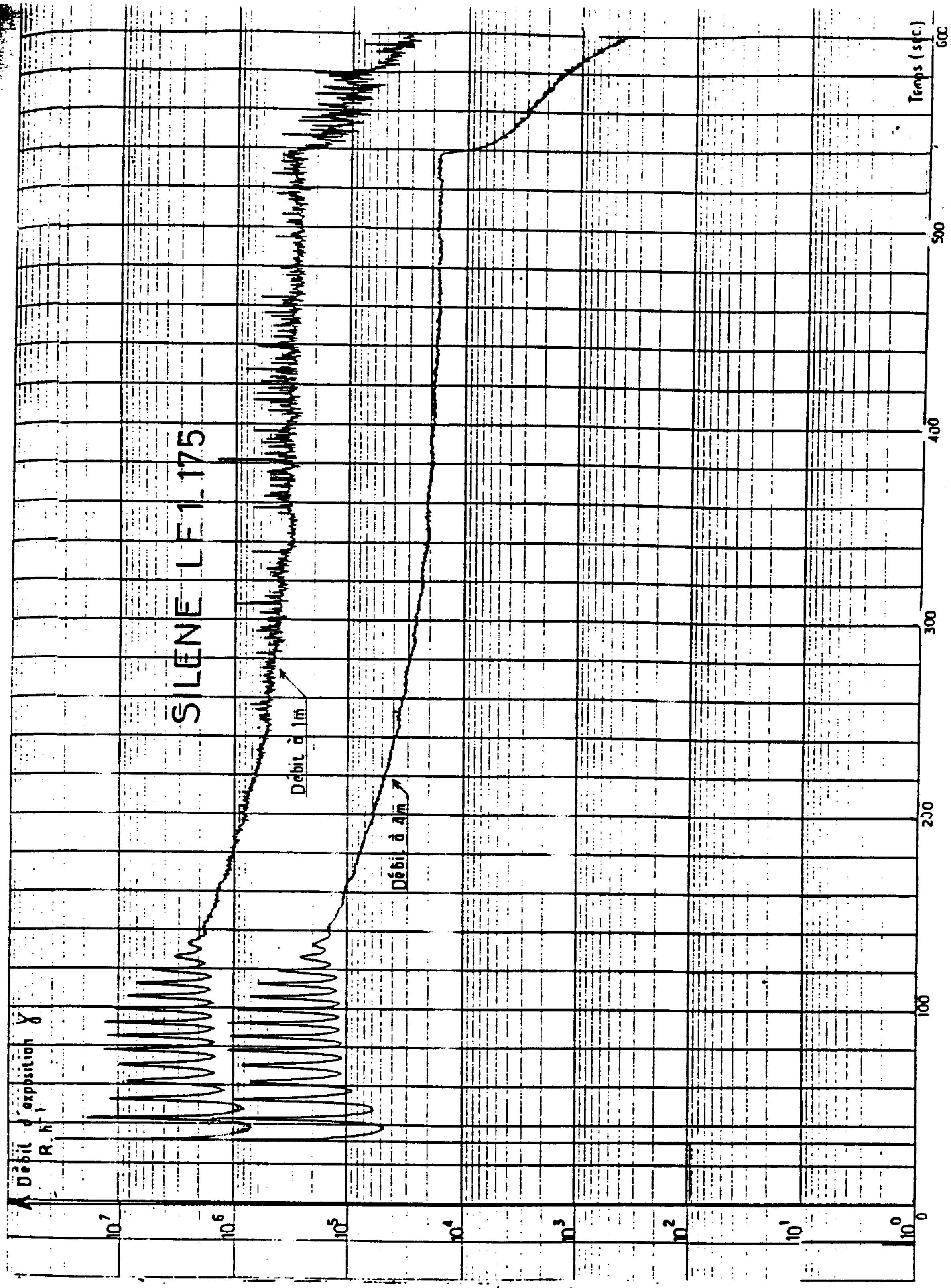
SILENE

Fig: 2 _Expérience du type " Ebullition"
Evolution de la puissance
(premiers pics)



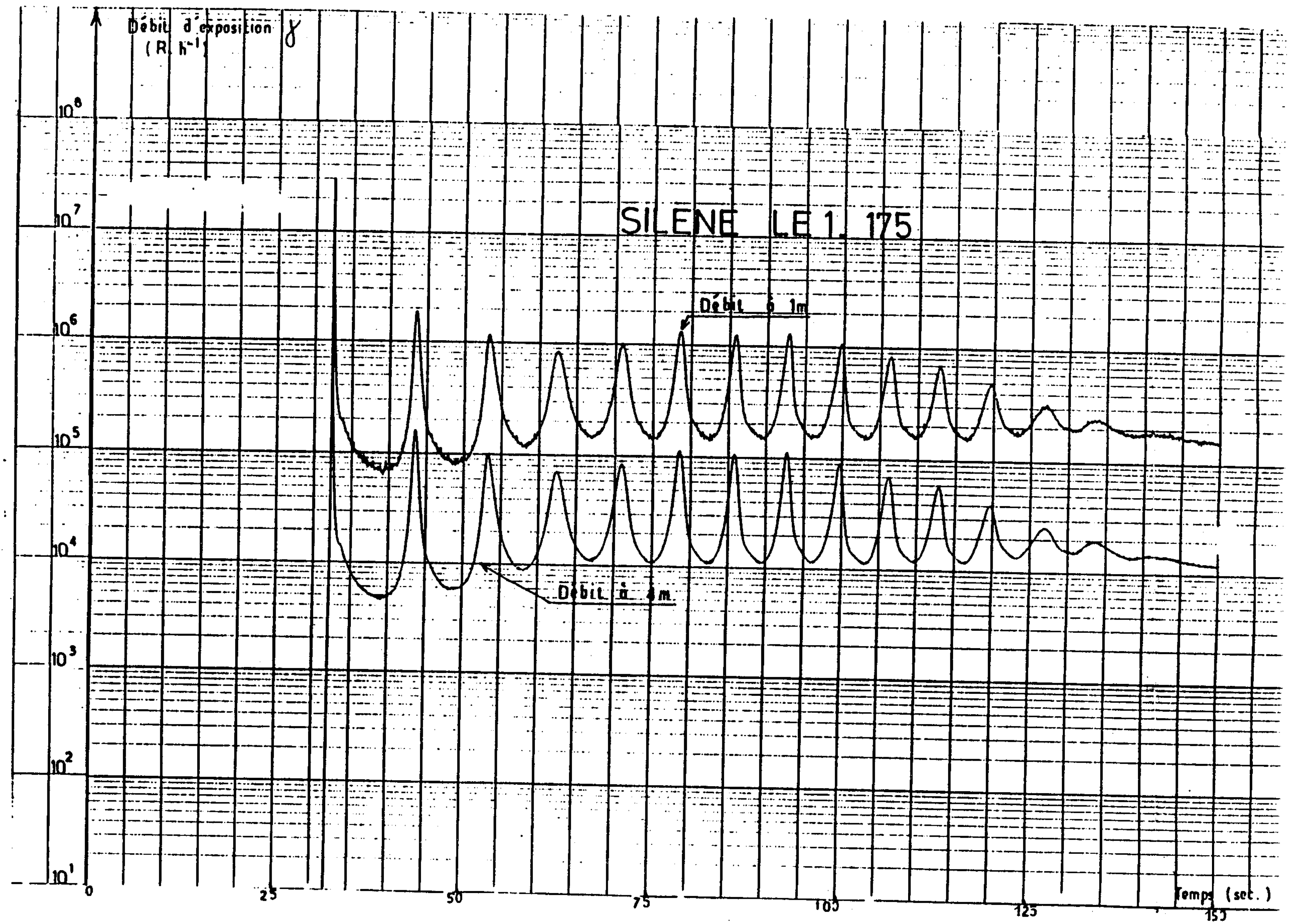
SILENE

Fig: 3 _Expérience du type " Ebullition"
Evolution de la puissance
(détail)



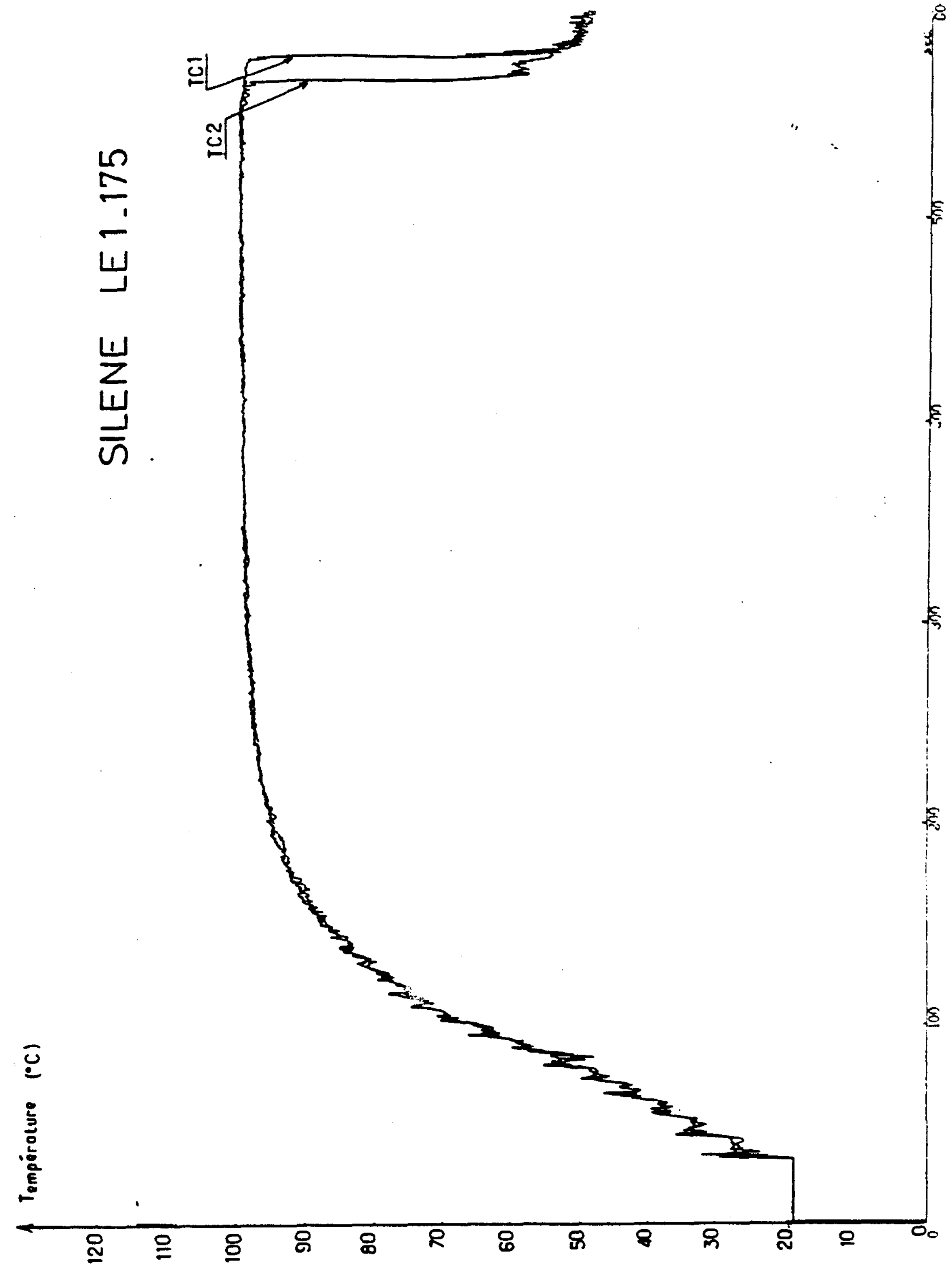
SILENE

Fig: 4 _Expérience du type " Ebullition"
Debits d'exposition γ á 1m et 4m de l'axe du réacteur
(toute l'expérience)



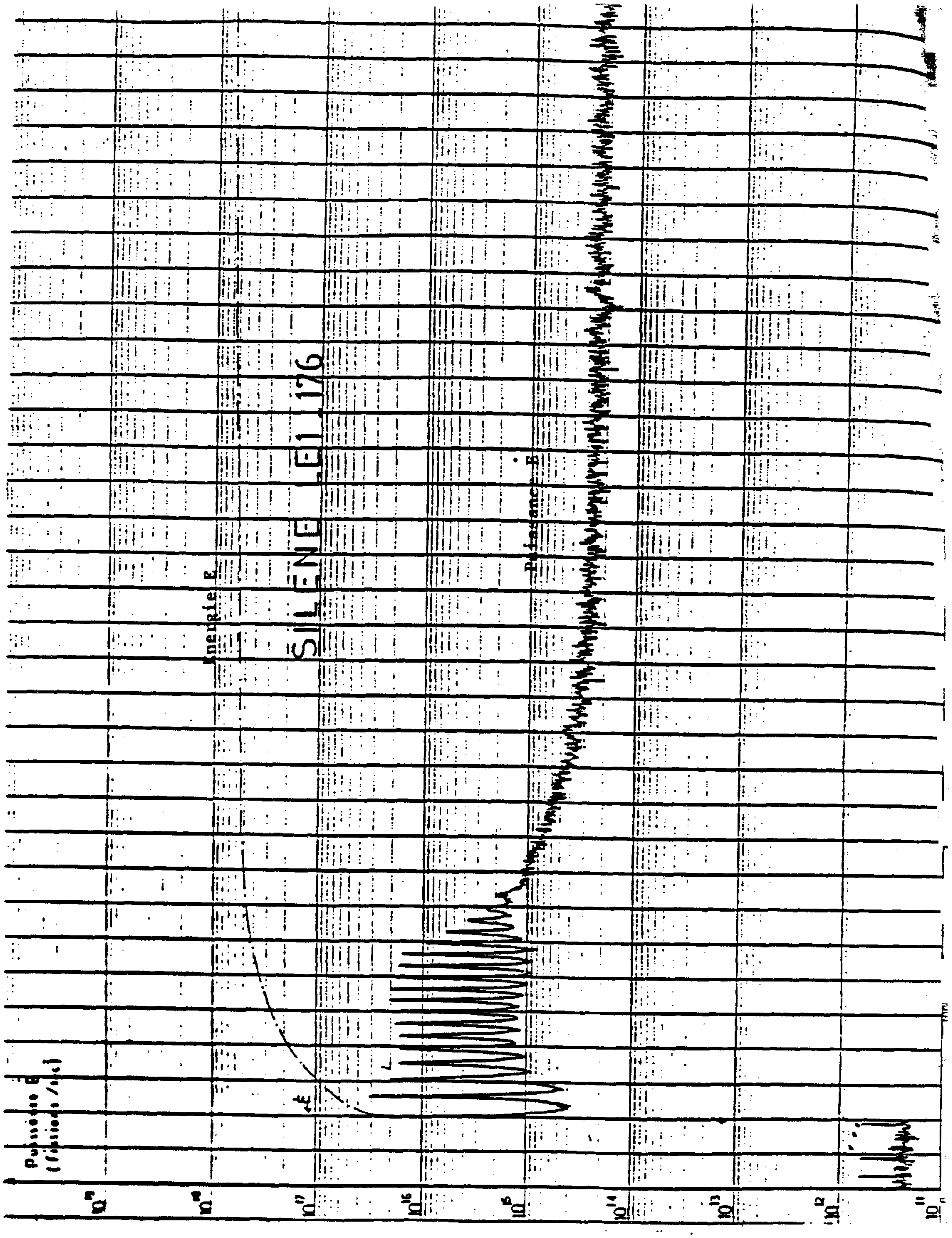
SILENE

Fig: 5 _Expérience du type "Ebullition"
Evolution de la puissance
(premiers pics)



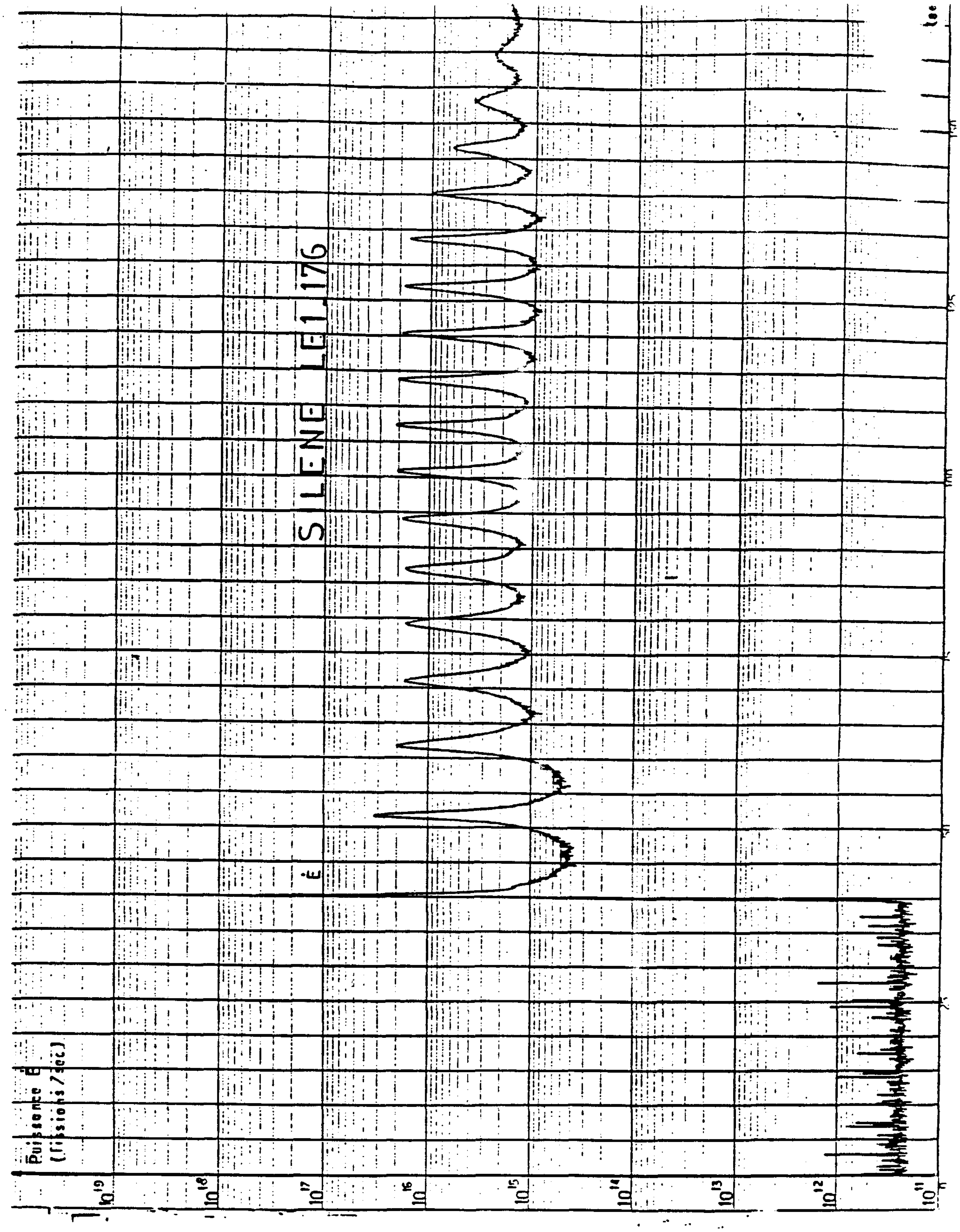
SILENE

Fig: 6 _Expérience du type " Ebullition"
Evolution de la température au sein du réacteur



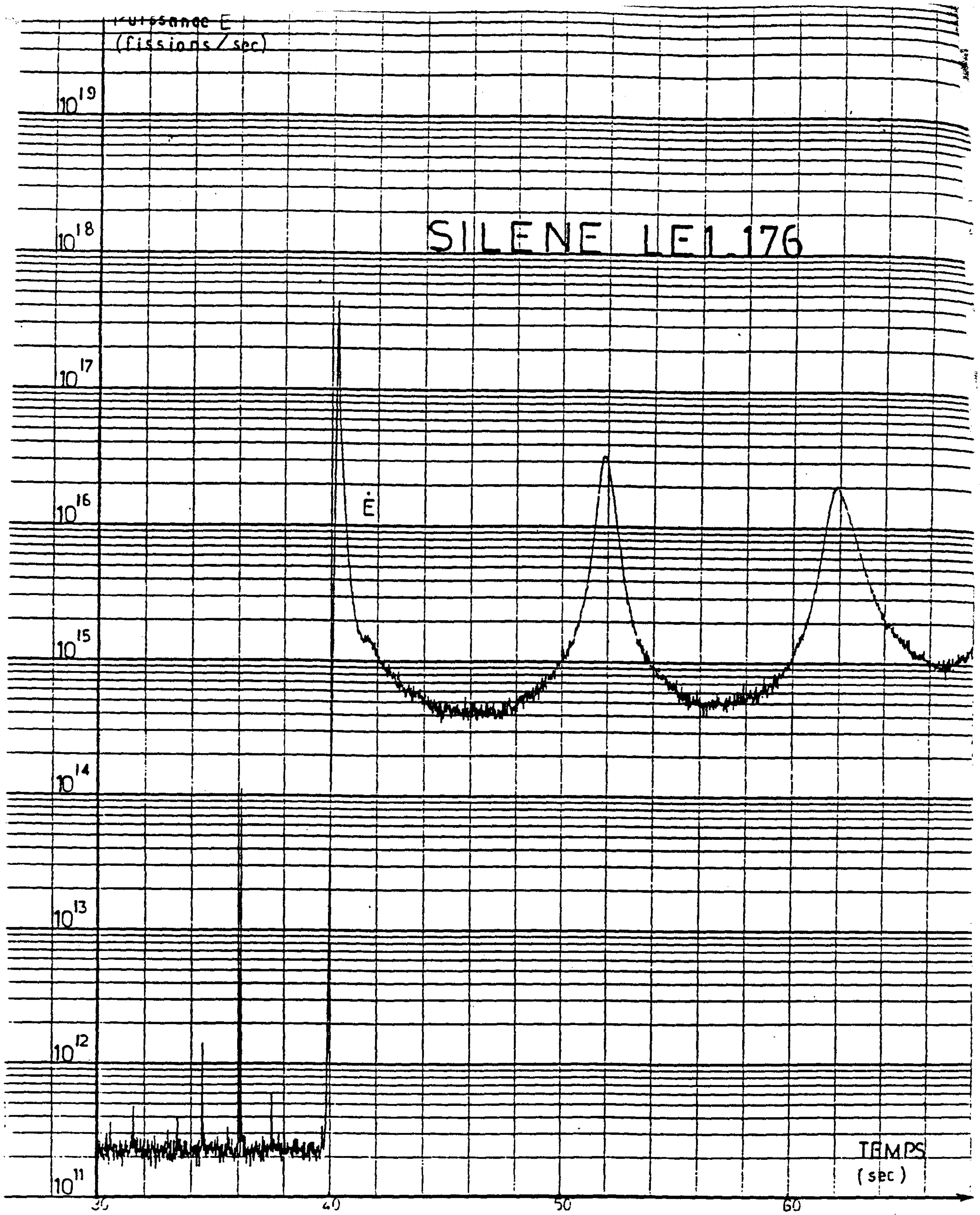
SILENE

Fig: 7 _Expérience du type " Ebullition"
Evolution de la puissance
(toute l'expérience)



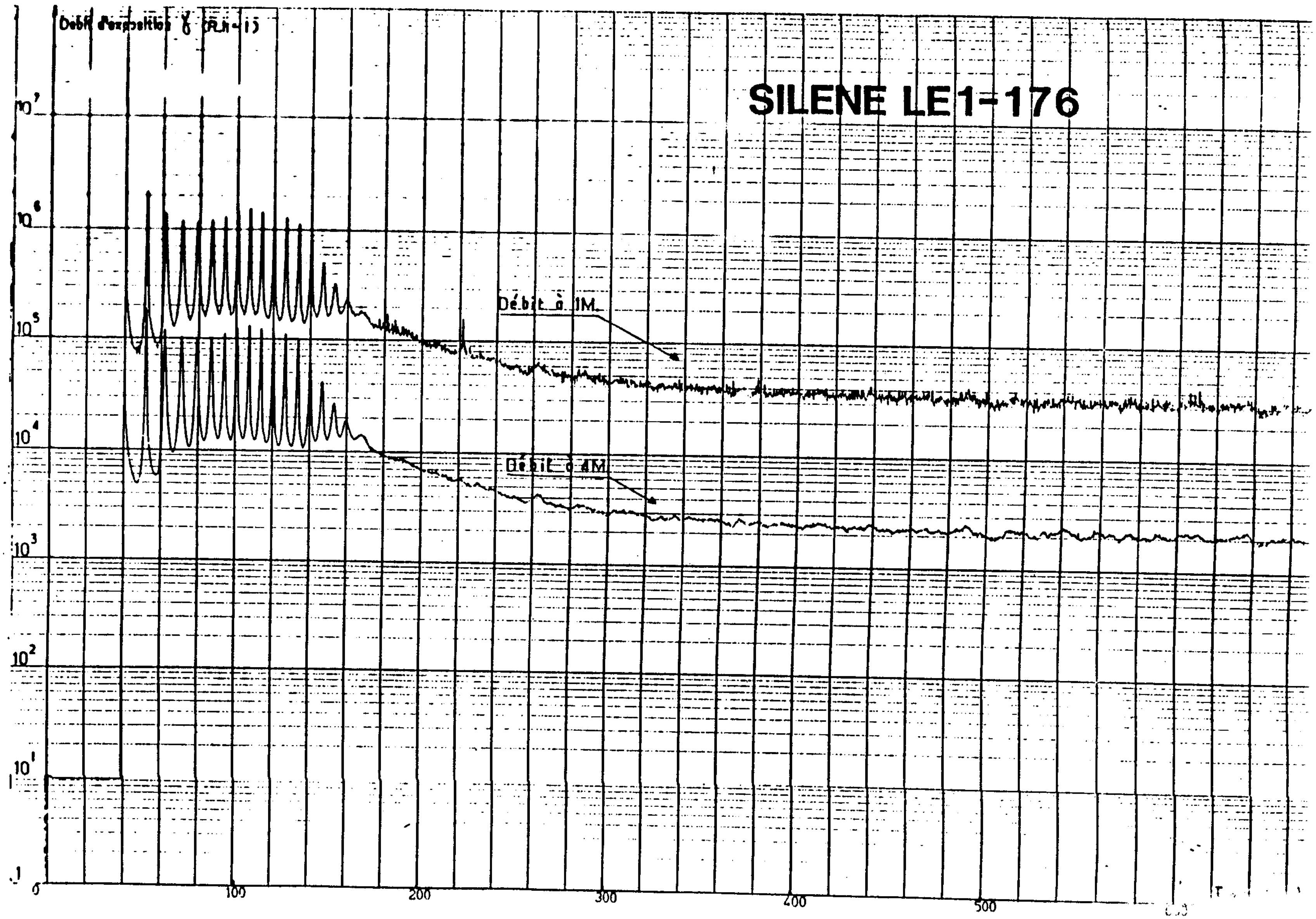
SILENE

Fig: 8 _Expérience du type " Ebullition"
Evolution de la puissance
(premiers pics)



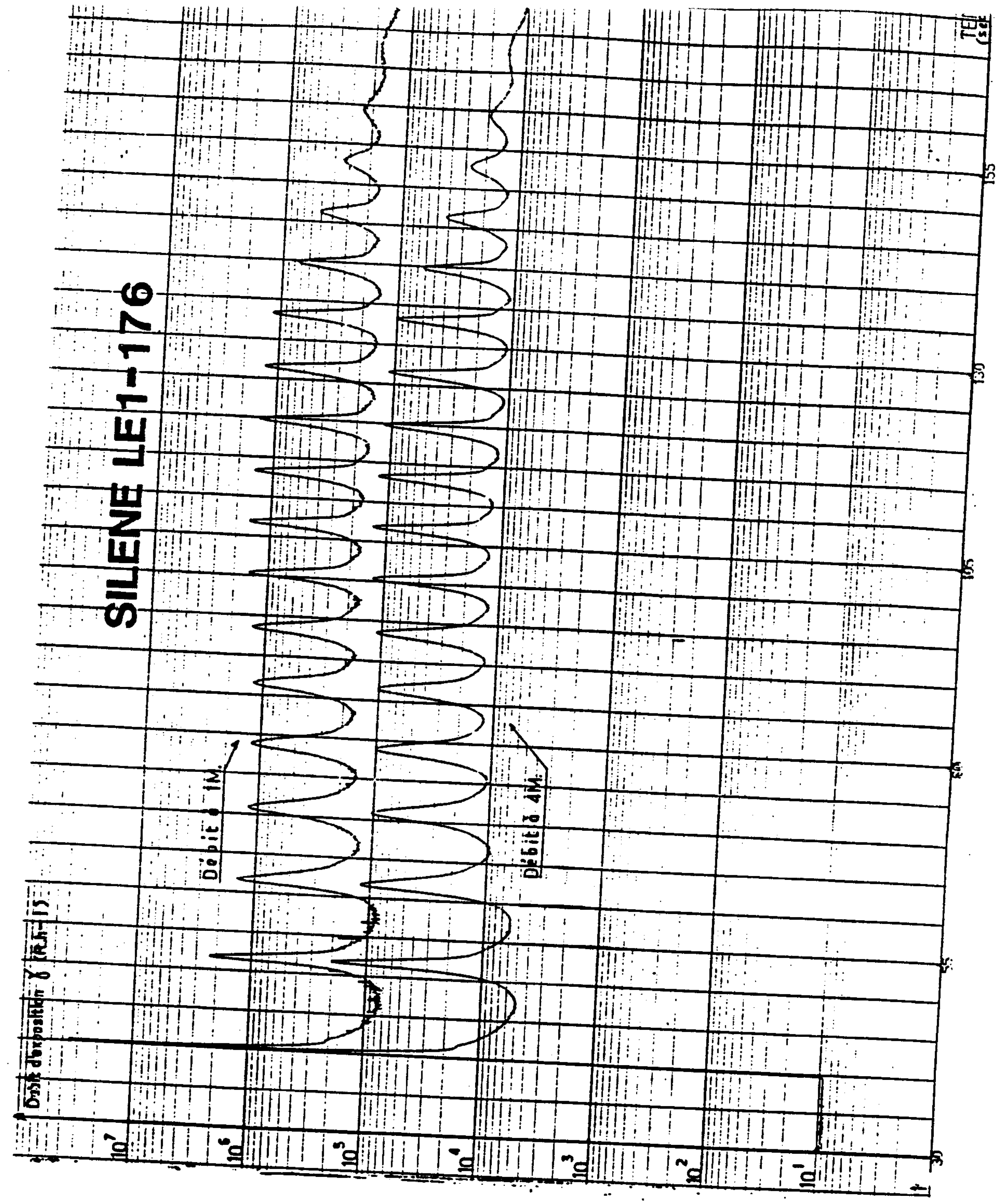
SILENE

Fig: 9 _Expérience du type " Ebullition"
Evolution de la puissance



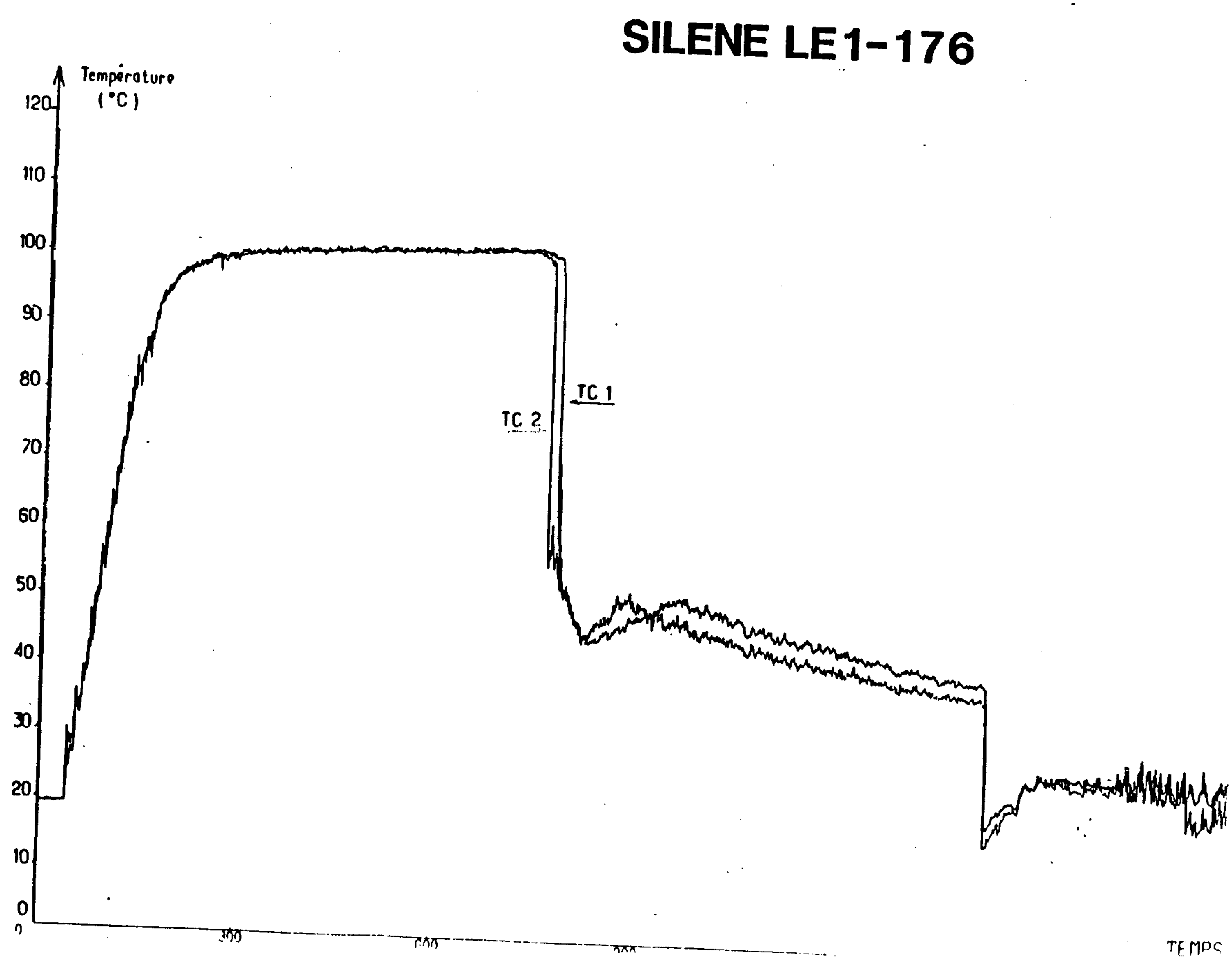
SILENE

Fig: 10 - Expérience du type " Ebullition"
Débits d'exposition γ à 1m et 4m de l'axe du réacteur
(toute l'expérience)



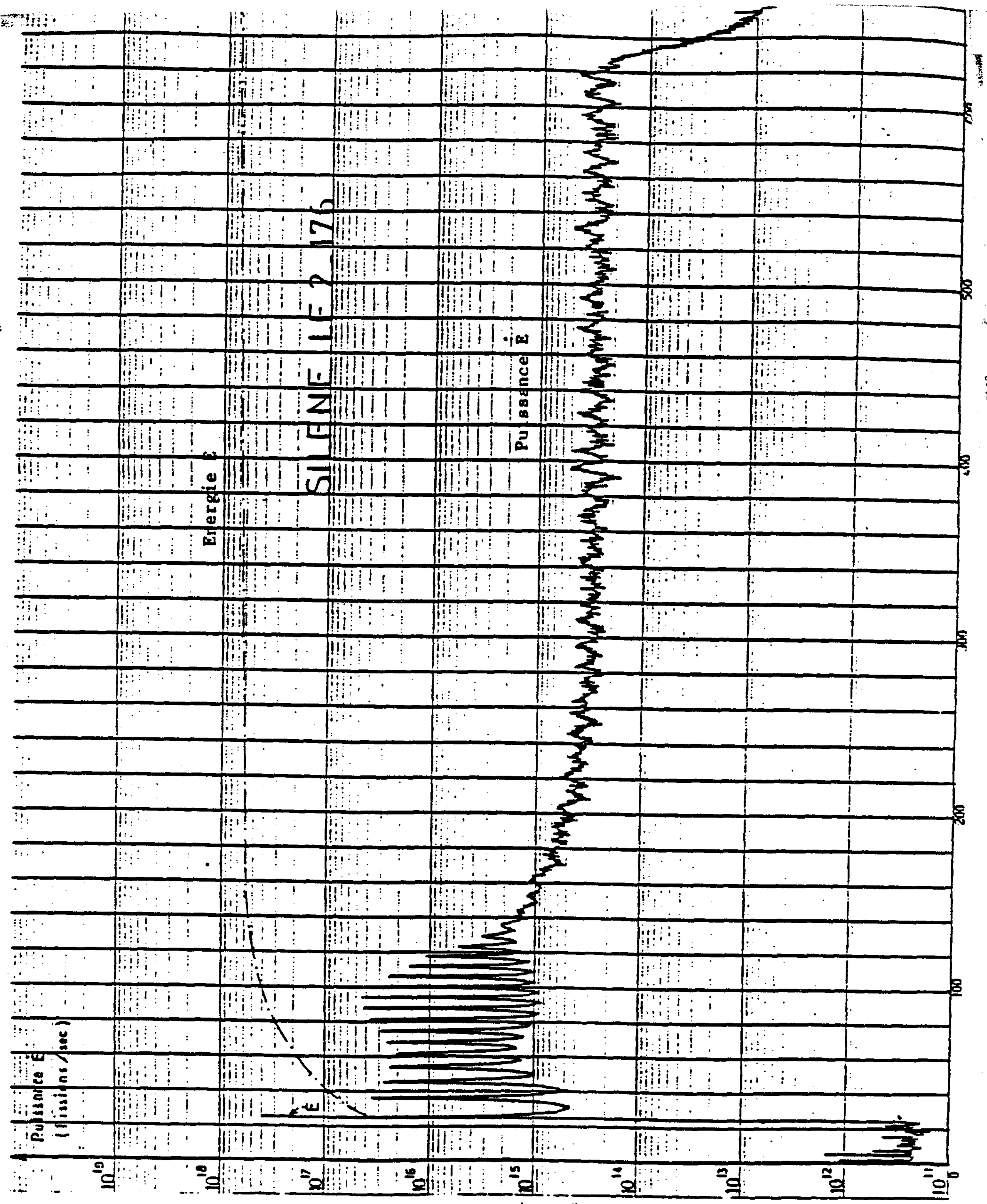
SILENE

Fig: 11 –Expérience du type " Ebullition"
Débits d'exposition γ á 1m et 4m de l'axe du réacteur
(premiers pics)



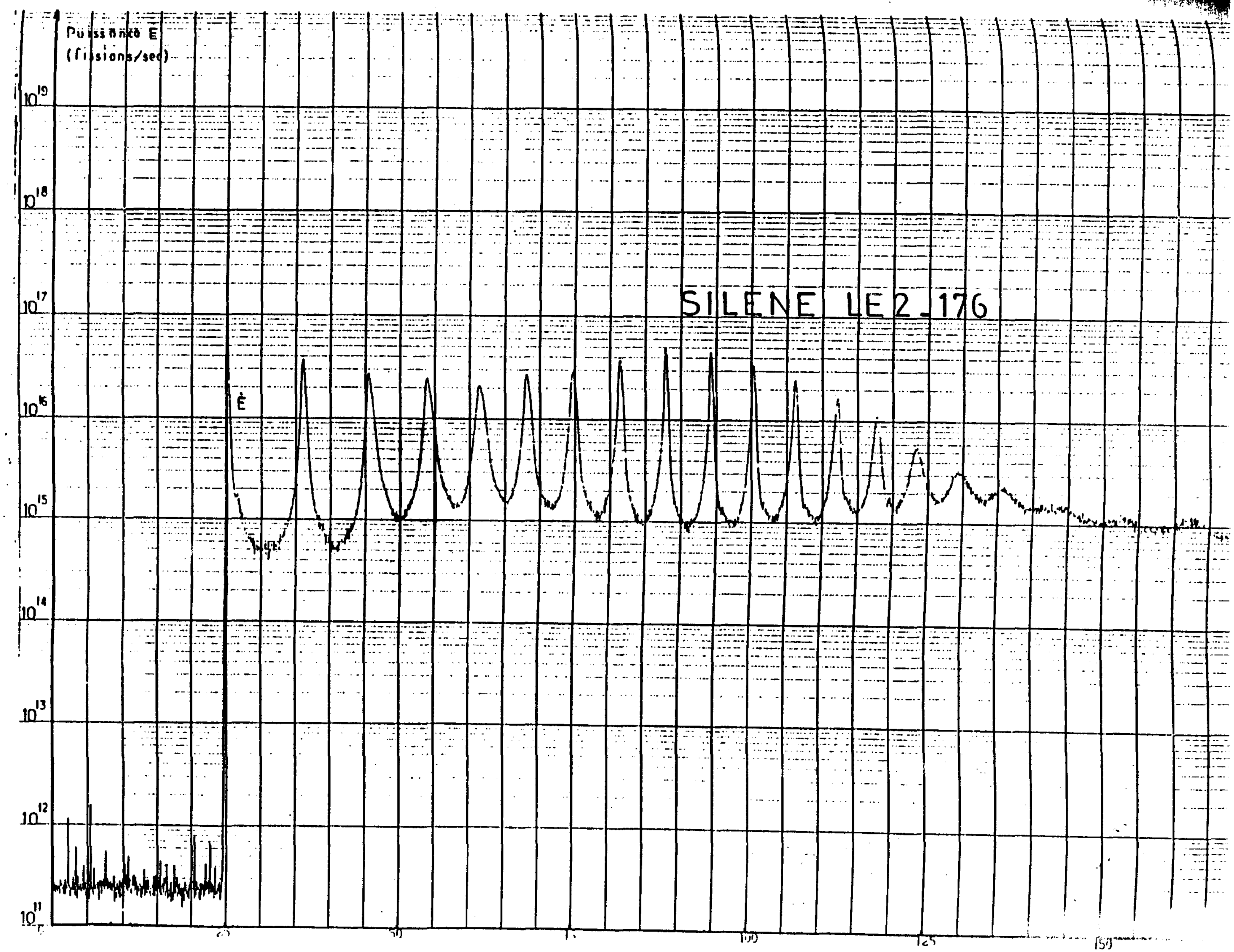
SILENE

Fig: 12 _Expérience du type " Ebullition"
Evolution de la température au sein du réacteur



SILENE

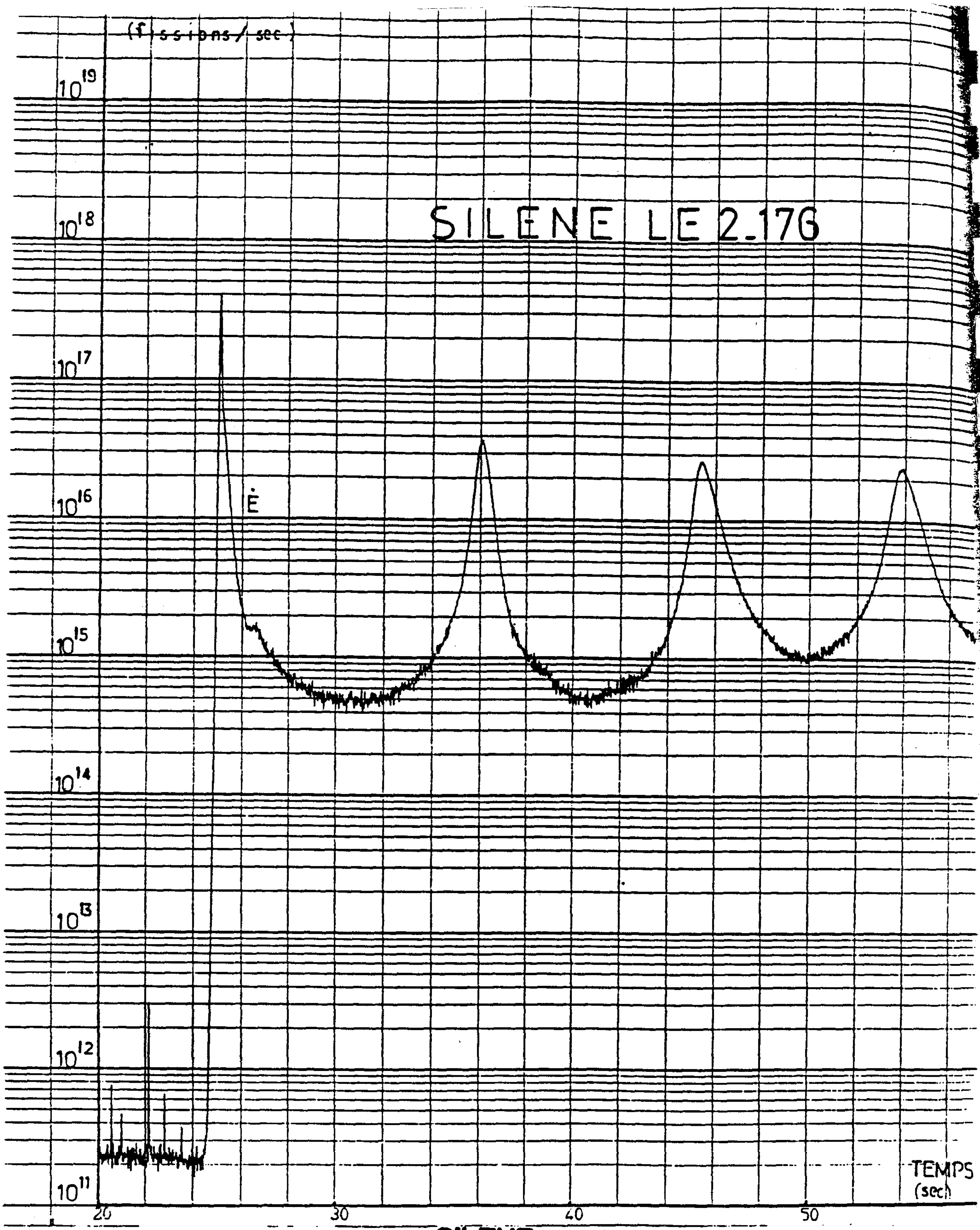
Fig: 13 _Expérience du type " Ebullition"
Evolution de la puissance
(toute l'expérience)



SILENE

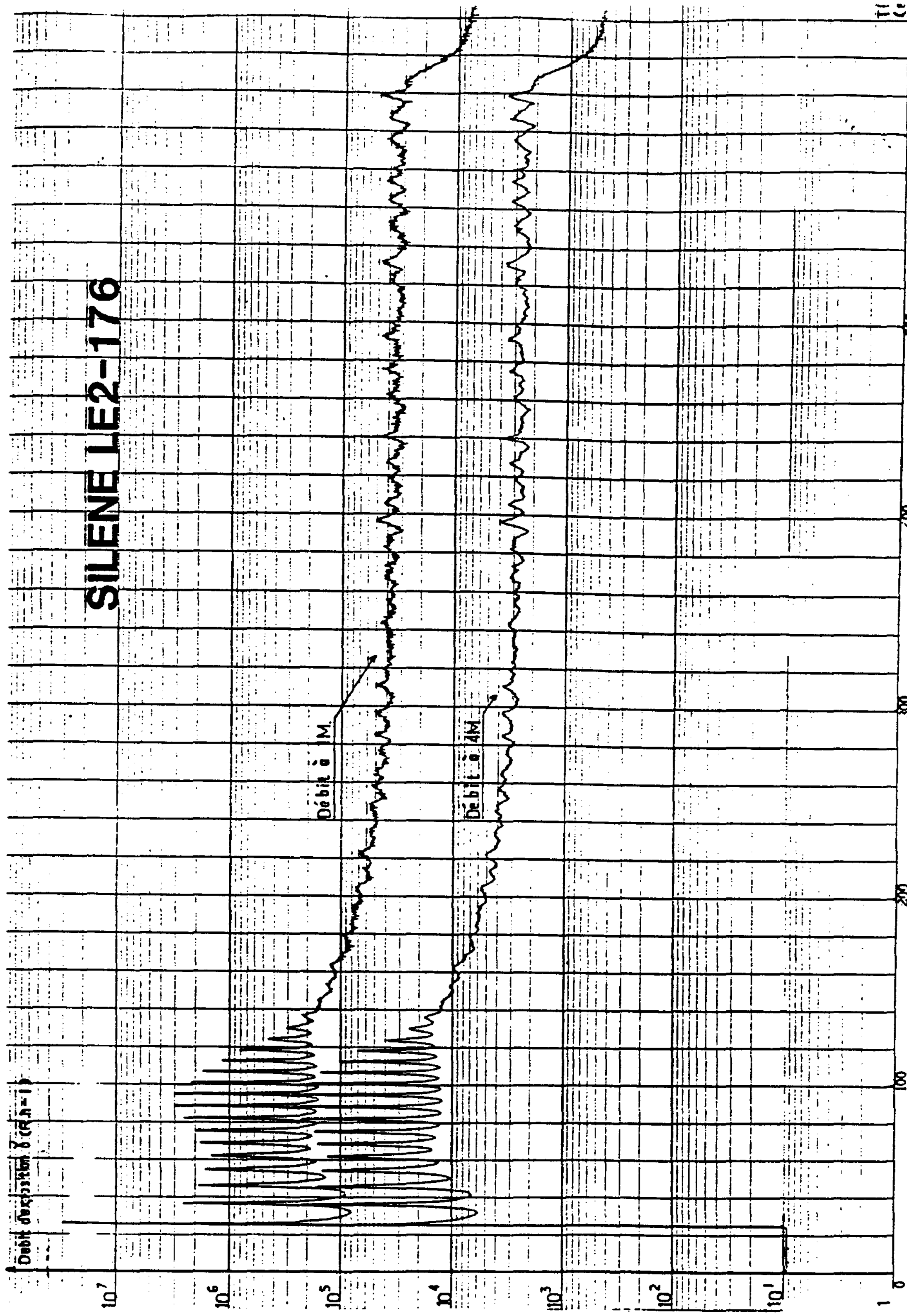
Fig: 14 _Expérience du type " Ebullition"

Evolution de la puissance



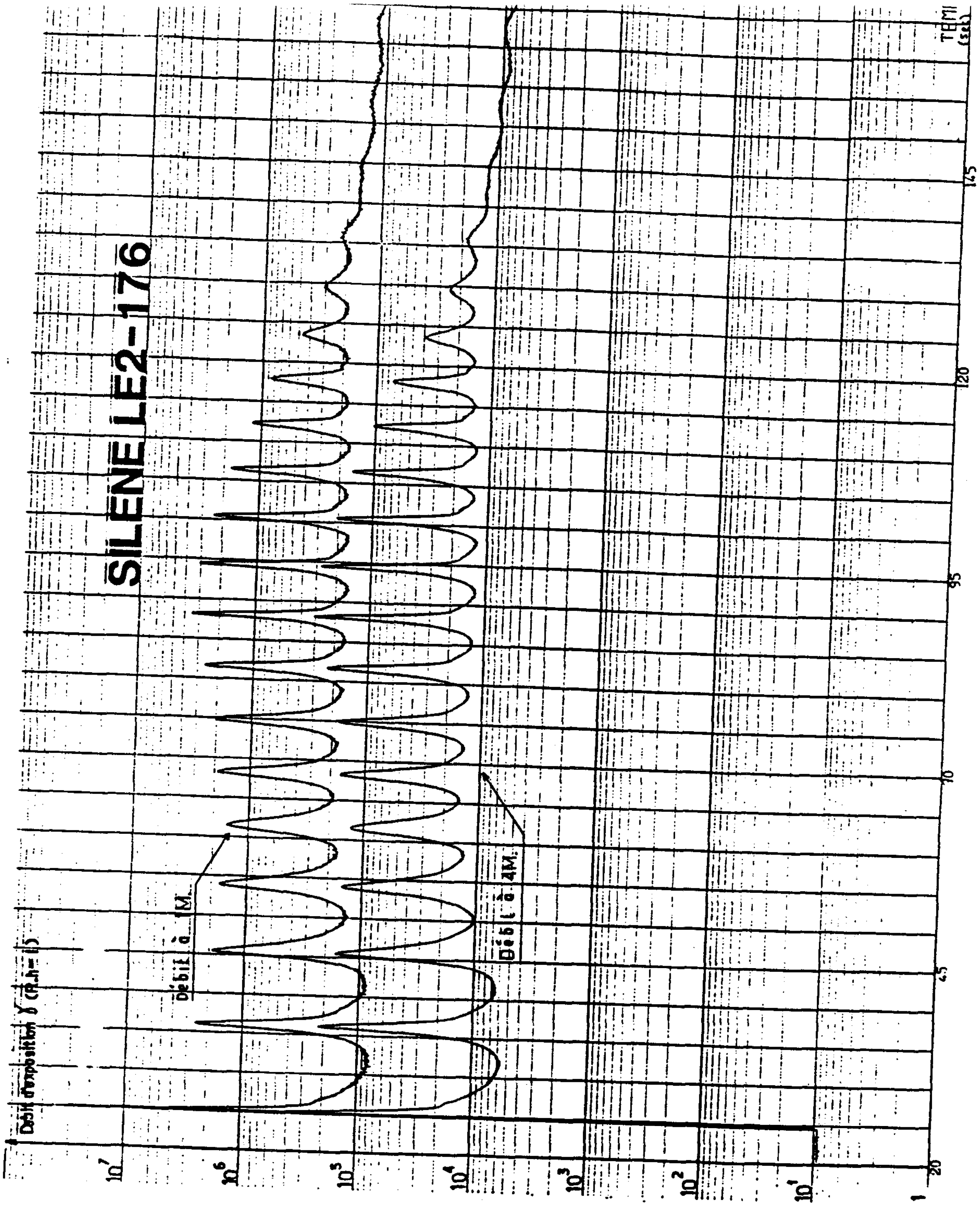
SILENE

Fig: 15 _Expérience du type " Ebullition"
Evolution de la puissance
(détail)



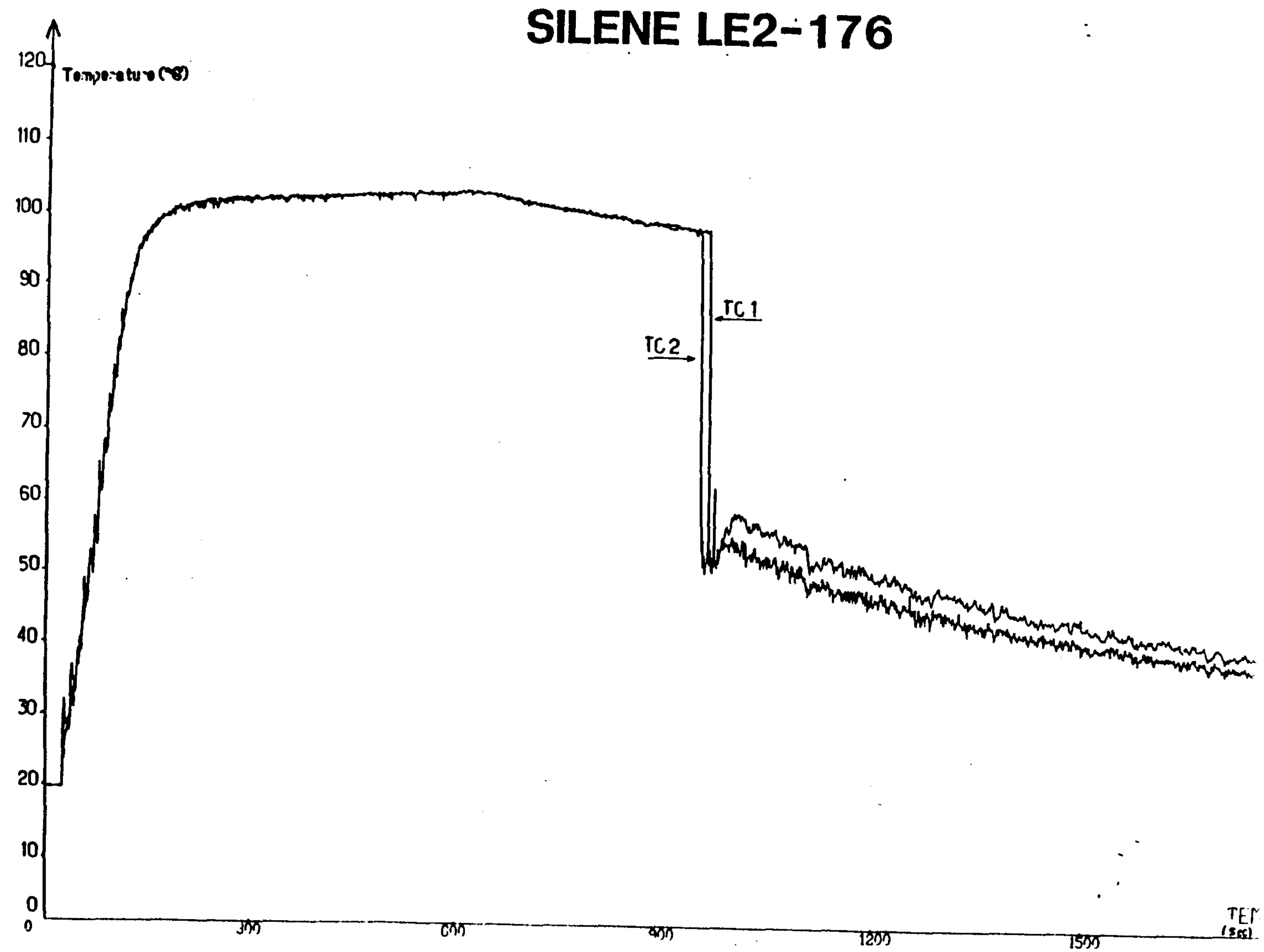
SILENE

Fig: 16 _Expérience du type " Ebullition"
Debits d'exposition γ á 1m et 4m de l'axe du réacteur
(toute l'expérience)



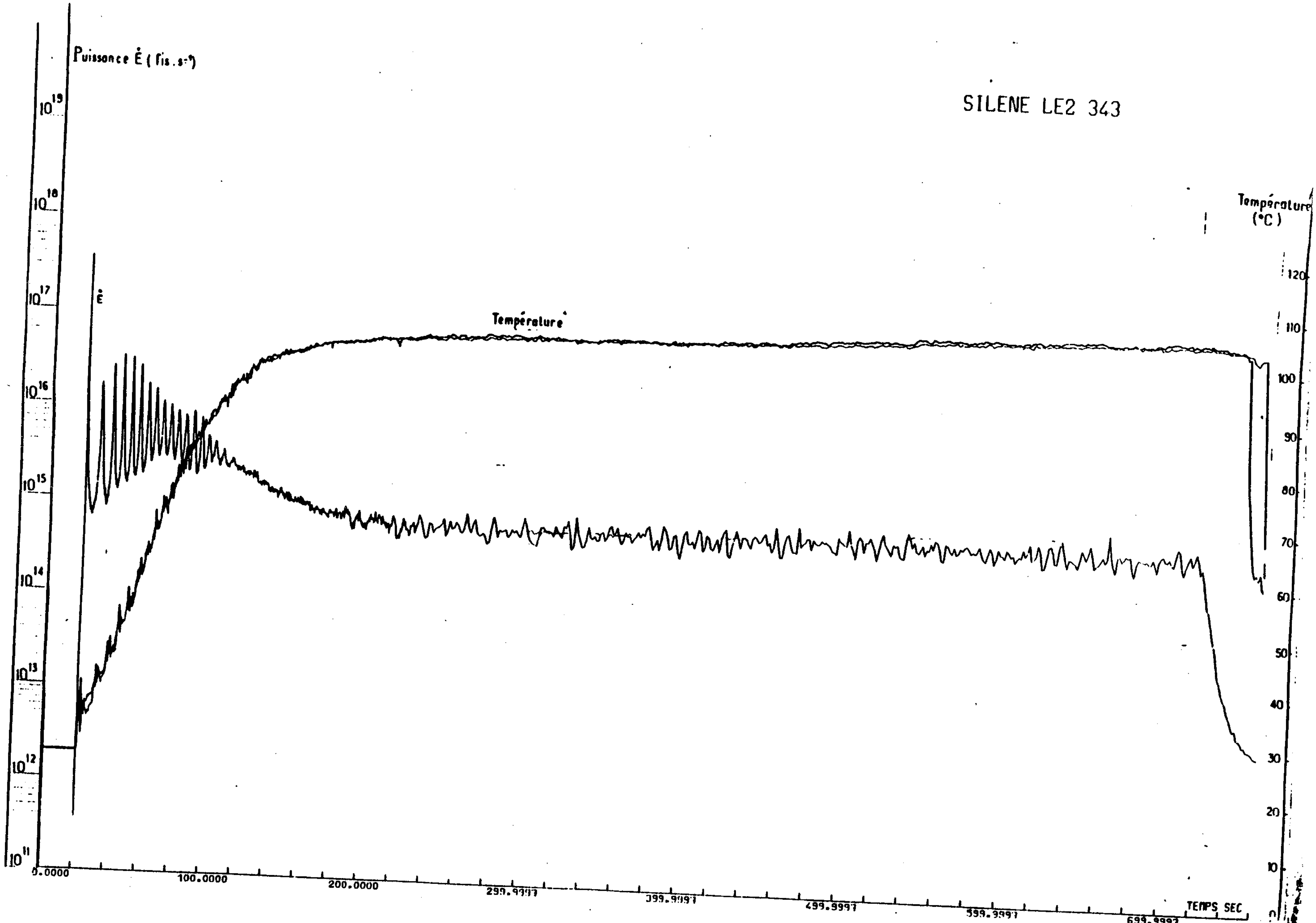
SILENE

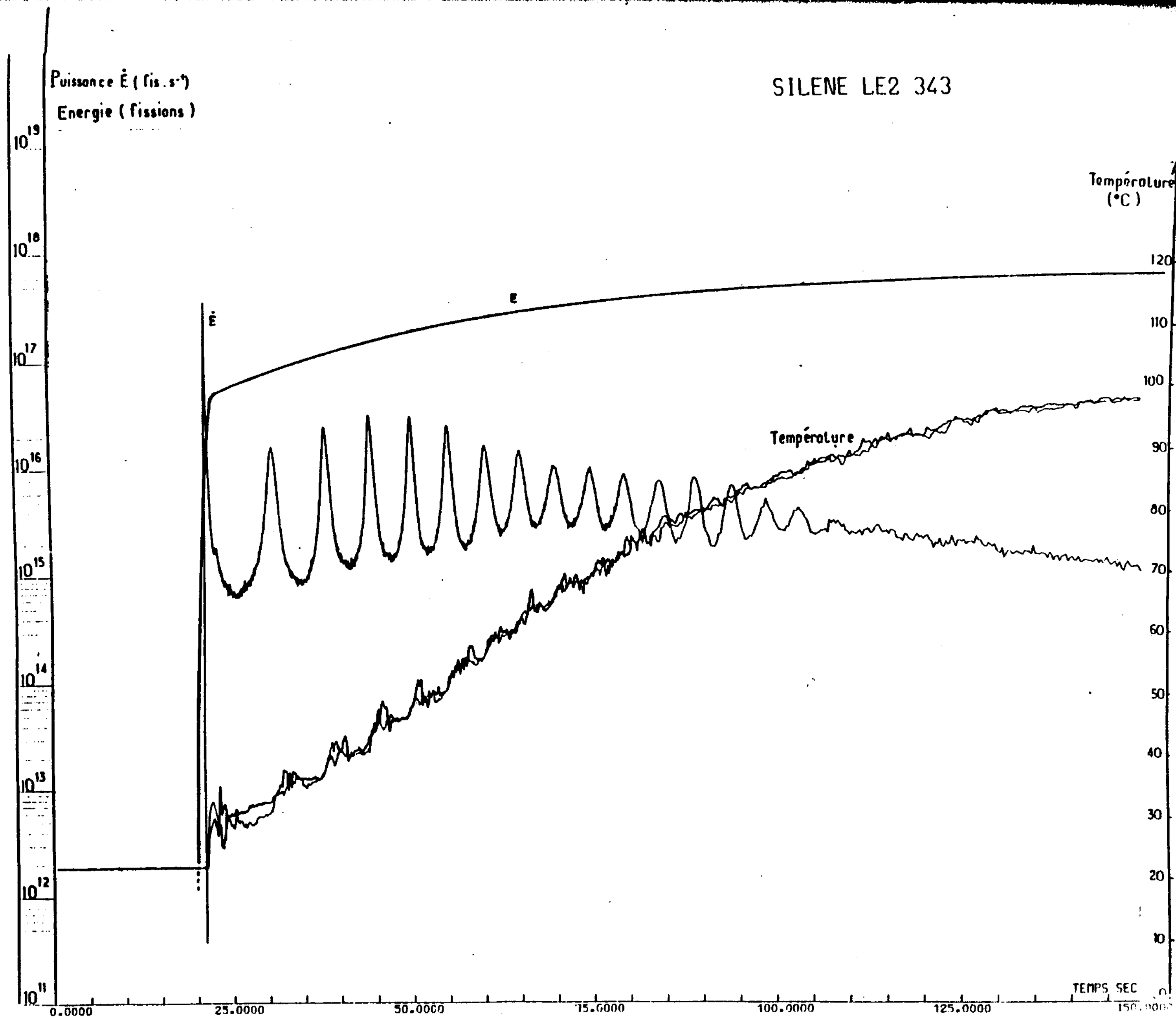
Fig: 17 – Expérience du type " Ebullition"
Debits d'exposition γ á 1m et 4m de l'axe du réacteur
(premiers pics)



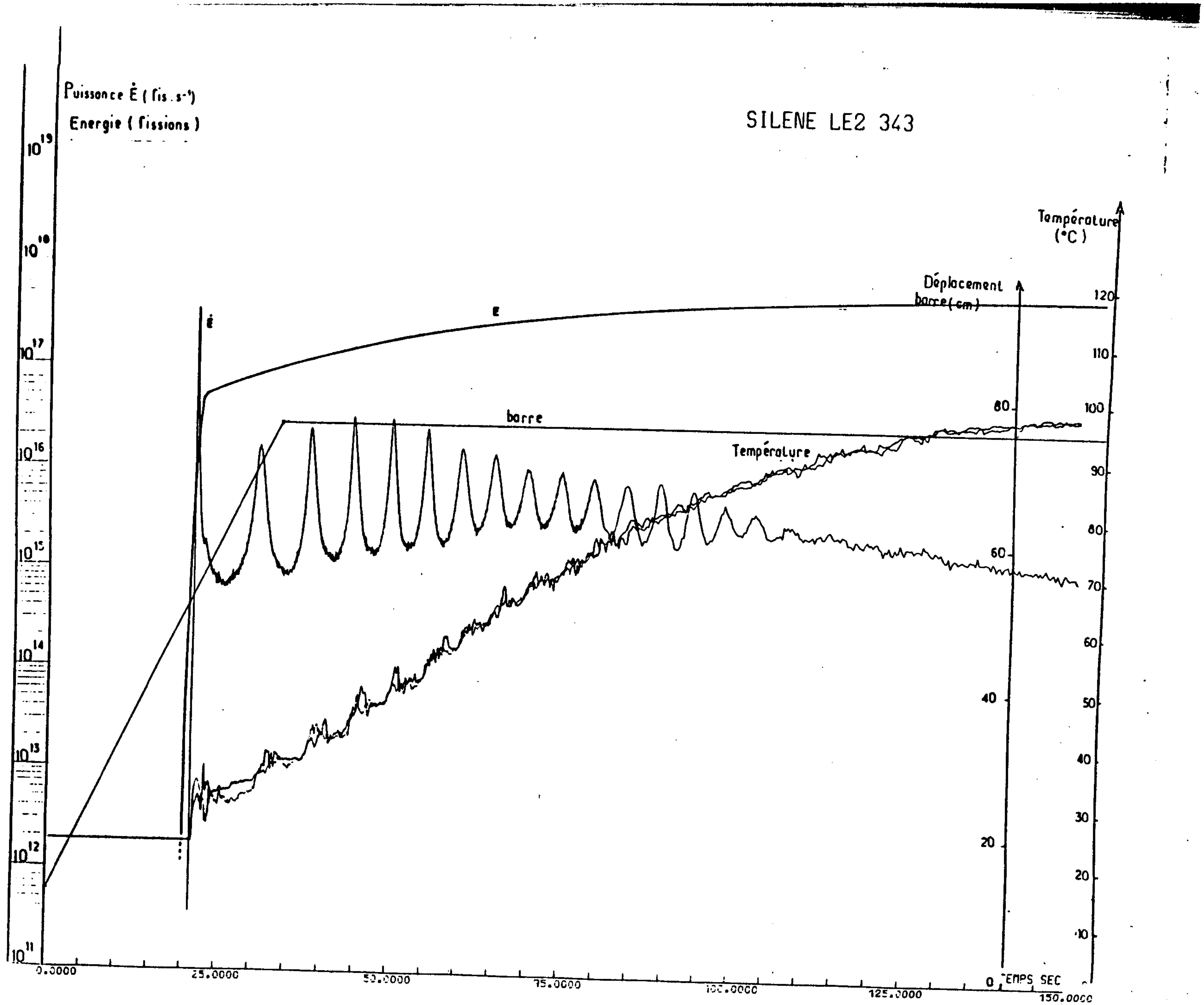
SILENE

Fig: 18 _Expérience du type " Ebullition"
Evolution de la température au sein du réacteur

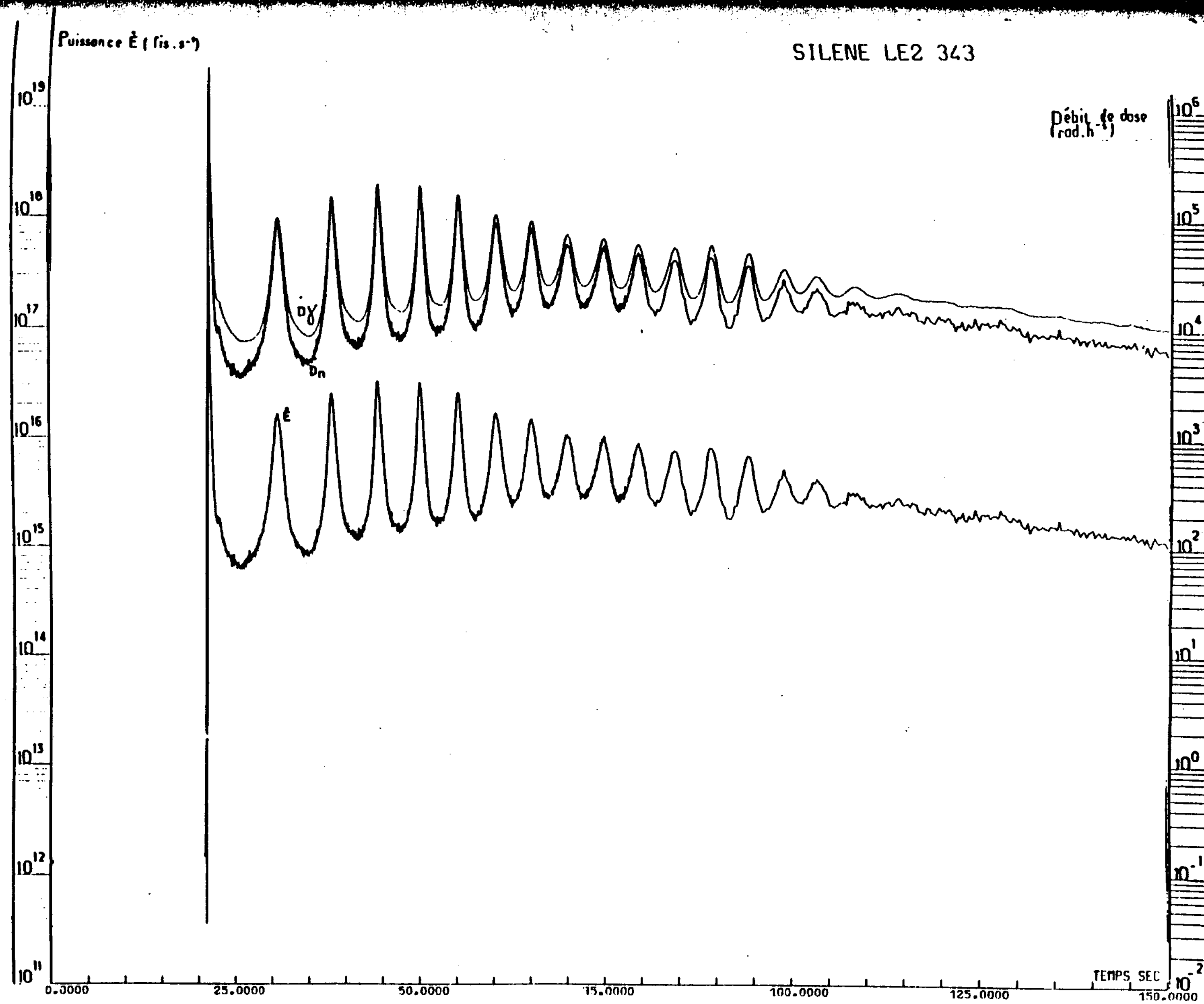

Puissance Ė (fis.s⁻¹)
SILENE LE2 343
10¹⁹
10¹⁸
10¹⁷
10¹⁶
10¹⁵
10¹⁴
10¹³
10¹²
10¹¹
Ė
Température
Température
(°C)
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0000
100.0000
200.0000
299.9997
399.9997
499.9997
599.9997
699.9997
TEMPS SEC



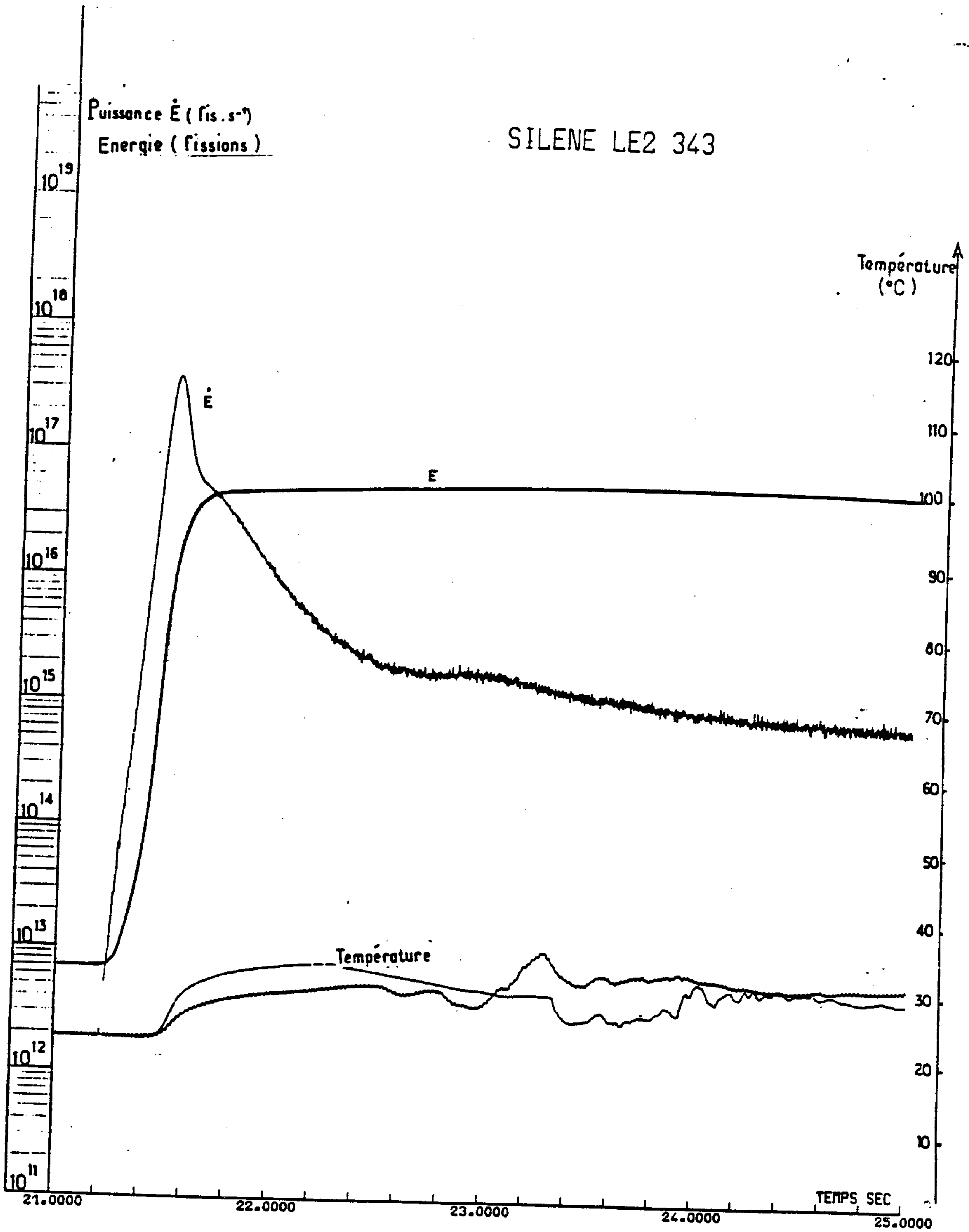
SILENE LE2 343
Puissance Ė (fis.s⁻¹)
Energie (fissions)
Température (°C)
Ė
E
Température
TEMPS SEC
0.0000
25.0000
50.0000
75.0000
100.0000
125.0000
150.0000



Puissance Ė (fis.s⁻¹)
Energie (fissions)
SILENE LE2 343
Température (°C)
Déplacement barre (cm)
Ė
E
barre
Température
10¹¹
10¹²
10¹³
10¹⁴
10¹⁵
10¹⁶
10¹⁷
10¹⁸
10¹⁹
0.0000
25.0000
50.0000
75.0000
100.0000
125.0000
150.0000
TEMPS SEC
0
20
40
60
80
10
20
30
40
50
60
70
80
90
100
110
120

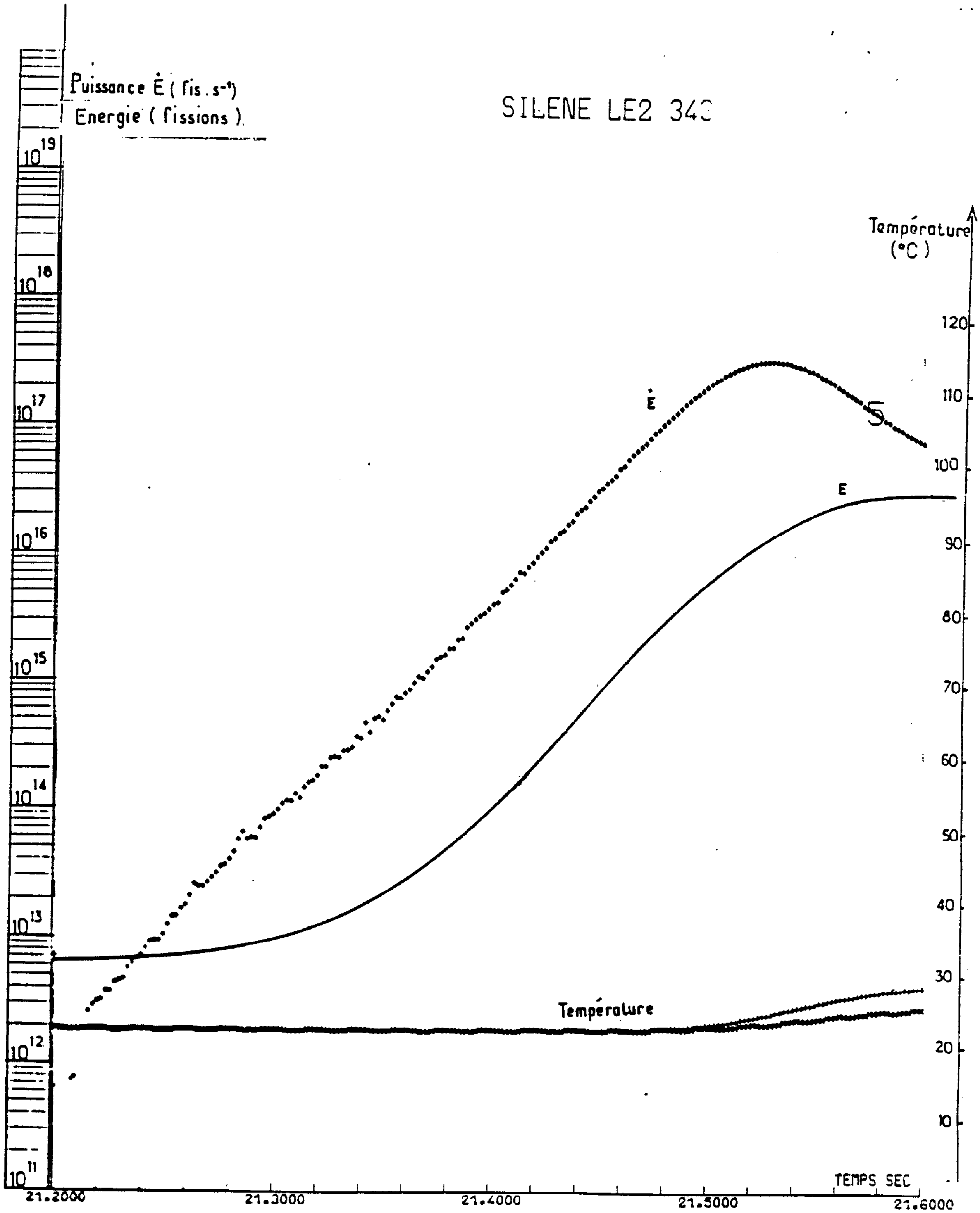


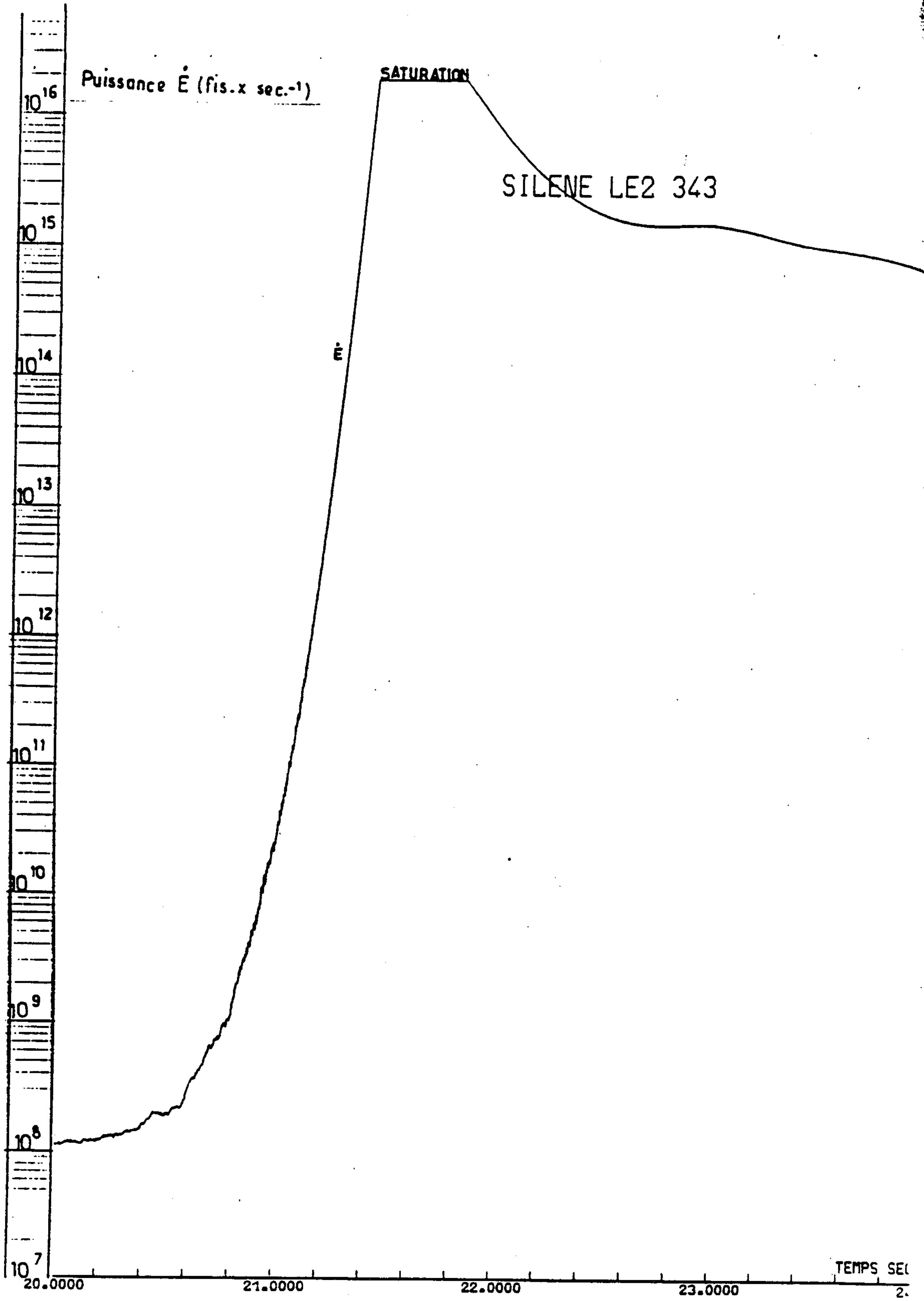
Puissance Ė (fis.s⁻¹)
SILENE LE2 343
Débit de dose (rad.h⁻¹)
Dγ
Dn
Ė
TEMPS SEC



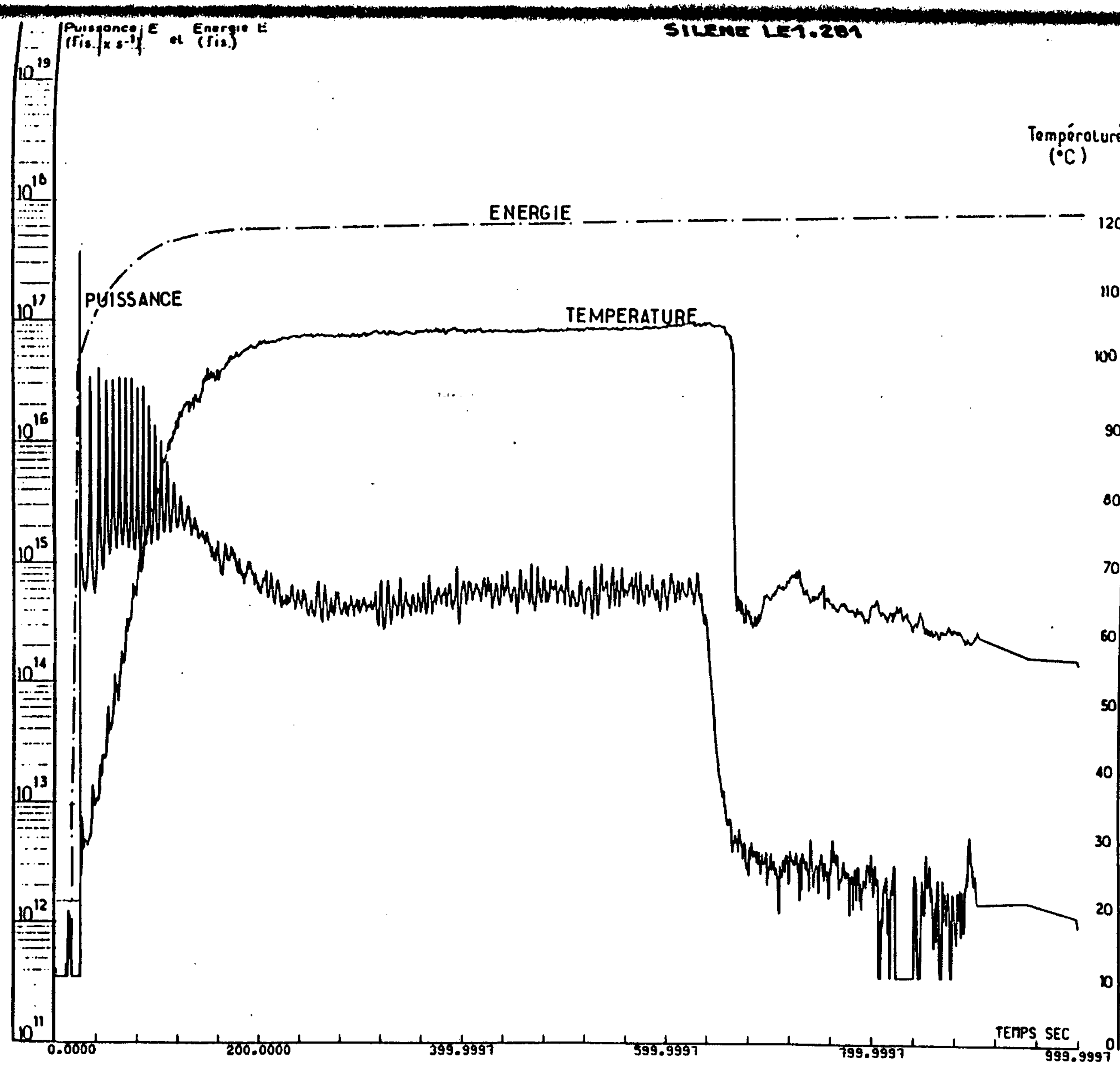
Puissance Ė (fis.s⁻¹)
Energie (fissions)
SILENE LE2 343
Température
(°C)
Ė
E
Température
TEMPS SEC
21.0000
22.0000
23.0000
24.0000
25.0000

SILENE LE2 34[illegible]





Puissance Ė (fis.x sec.-1)
SATURATION
SILENE LE2 343
Ė
10 16
10 15
10 14
10 13
10 12
10 11
10 10
10 9
10 8
10 7
TEMPS SE
20.0000
21.0000
22.0000
23.0000


SILENE LE1.281
Puissance E (fis. x s-1) et Energie E (fis.)
ENERGIE
PUISSANCE
TEMPERATURE
Température (°C)
TEMPS SEC
0.0000
200.0000
399.9997
599.9997
799.9997
999.9997

APPENDIX 1

RESULTS OBTAINED ON SILENE REACTOR WITH A URANIUM CONCENTRATION OF 220 $g.l^{-1}$

1 - Preamble

A series of experiments was carried out in 1981 and 1982 using a uranium concentration of 220 $g.l^{-1}$ on the Silene reactor within the framework of studies on solution criticality accidents, in order to acquire experimental data in the following areas:

1. Maximum release of gaseous fission products when concentrated uranium solutions are in the boiling state.

2. Neutron and gamma radiation dosimetry associated with this type of configuration (concentrated medium, geometry different from an orthogonal cylinder).

3. Characterization of the power level of the boiling "steps".

The results presented here cover mainly kinetics (the effect in terms of reactivity of 1 millimeter of solution, period and power of the first peak), since the rest of the information was summarized previously in other documents.

2 - Presentation of results

Because the experiments were carried out on tank no. 1 at Silene during general calibration of the reactor (Ref. 1 and 2), and more recently on core no. 2 using a slightly different configuration (different thickness in the tank bottom and different fissile solution acidity), it is quite normal that certain differences will appear in critical characteristics of Silene with the 220 $g.l^{-1}$ concentration.

The results are presented in the following manner :

1. Neutron calculations,

2. Critical characteristics and effects of one millimeter,

3. Kinetic experiments on core no. 2,

4. Dosimetry.

3 - Neutron calculations

These calculations were made by the DAS/SEC at the time of the first calibration of Silene using the Moret code.

- Characterisics of the fissile solution:

C_{U_t} = 220 g.l^{-1} ^{235}U enrichment = 92.7%
Acidity = 2.84 M
NO_3- = 4.71 M
Density = 1.386

In terms of number of atoms per cm^3, this gives:

Number of ^{235}U atoms	5.253 10^{20}
Number of ^{238}U atoms	3.821 10^{19}
Number of H atoms	5.802 10^{22}
Number of N atoms	2.838 10^{21}
Number of O atoms	3.780 10^{22}

Calculation of k_{eff} (Moret results)

Solution height	20	22	22.4	24	26.4	30	36.4	40
k_{eff}	0.931	0.961	0.965	0.999	1.025	1.065	0.110	1.127

The evolution of k_{eff} as a function of the solution height is illustrated in figure 1.

Lifetime of prompt neutrons ℓ = 12.5 μs for H = 24 cm.

Taking into account the fact that the fissile solution heights used for the kinetic experiments were higher, let ℓ = 13 μs for the Nordheim calculations.

- Characteristics of delayed neutrons:

GROUP	1	2	3	4	5	6
ξi βi % λi s^{-1}	1.38 0.021 0.0124	1.33 0.139 0.0305	1.35 0.126 0.111	1.34 0.252 0.301	1.35 0.074 1.13	1.20 0.026 3.00

$$\beta_{eff} = \sum_{i=1}^{6} \xi_i \times \beta_i = 853 \text{ pcm}$$

Graph no. 2 illustrates the Nordheim relationship between reactivity and doubling time T_2 for the Silene configuration at 220 $g.l^{-1}$.

4 - Critical characteristics and eff·cts on reactivity of one millimeter of solution

Core No. 1:

fissile solution C_{U_t} = 220 g.l^{-1}
H^+ = 2.84 M
d = 1.3860

fissile solution height H_c = 25.00 cm
(core tank bottom thickness 20 mm)

Effect of one millimeter $\frac{\Delta\rho}{\Delta H}$

Experiment No.	T_2 s	ΔH mm	Δρ		Δρ/ΔH	
			p.c.m.	$	pcm/mm	$/mm
D4 - 01	45.6	0.87	116	0.136	136	0.158
D5 - 01	15.7	1.68	228	0.267	136	0.159
D6 - 01	6.7	2.54	347	0.406	137	0.160
D7 - 01	3.75	3.19	435	0.509	136	0.160

Core No. 2:

Fissile solution C_{U_t} = 217.9 g.l^{-1}
H^+ = 2.84 M
d = 1.3562

core bottom thickness = 36 mm

critical height H_c = 23.27 cm

Effects of one millimeter $\frac{\Delta\rho}{\Delta H}$

Experiment No.	T_2 s	ΔH mm	$\Delta\rho$ p.c.m.	$\Delta\rho$ $	$\frac{\Delta\rho}{\Delta H}$ pcm/mm	$\frac{\Delta\rho}{\Delta H}$ $/mm
D1 - 115	31.1	0.97	151	0.177	156	0.182
D2 - 195	9.3	2.0	298	0.349	149	0.175
D3 - 195	3.9	2.91	430	0.504	148	0.173
D1 - 200	39.7	0.85	127	0.149	149	0.175
D2 - 200	13.9	1.67	243	0.285	146	0.171
D3 - 200	6.5	2.41	350	0.410	145	0.170
D4 - 200	3.36	3.09	454	0.532	147	0.172

5. Results of kinetic experiments

These results are recorded in Table 1 and illustrated on graphs 3 to 35.

The notations used are the following:

U_t : Total uranium concentration (in $g.l^{-1}$) (92.7 % ^{235}U enriched uranium)

H_c : Delayed critical height (in cm)

V_c : Critical volume (in liters)

M_c : Critical mass in U_t (in kg)

H_f : Final fissile solution height (in cm)

V_f : Final volume (in liters)

ΔH : Excess solution introduced above H_c, i.e. H_f - H_c (in nm)

N_f : Total number of fissions

Δkp : Total potential reactivity inserted in the core

Δk_{eff_1} : Effective reactivity present at the first peak

: Mean rise in temperature of the fissile solution at the end of the experiment (in °C), θ_i designating the initial temperature and θ_f the temperature reached at the equilibrium state t_e

T_2 : Doubling time of power rise (in s)

T_e : Period of divergence (in s)

ω : Reciprocal of period (in s^{-1})

E : Maximum power at the top of the first peak (in fissions/s)

t_1 : Time corresponding to the first peak

Δp : Dynamic pressure wave on the core tank bottom during the first peak (relative value)

E_{p1} : Energy integrated up to the bottom of the first peak (in fissions)

E_{p2} : Total energy integrated during the first peak (including residual power)

t_{eq} : Time required for the system to reach temperature equilibrium

E_{eq} : Energy integrated at time t_{eq} (in fissions).

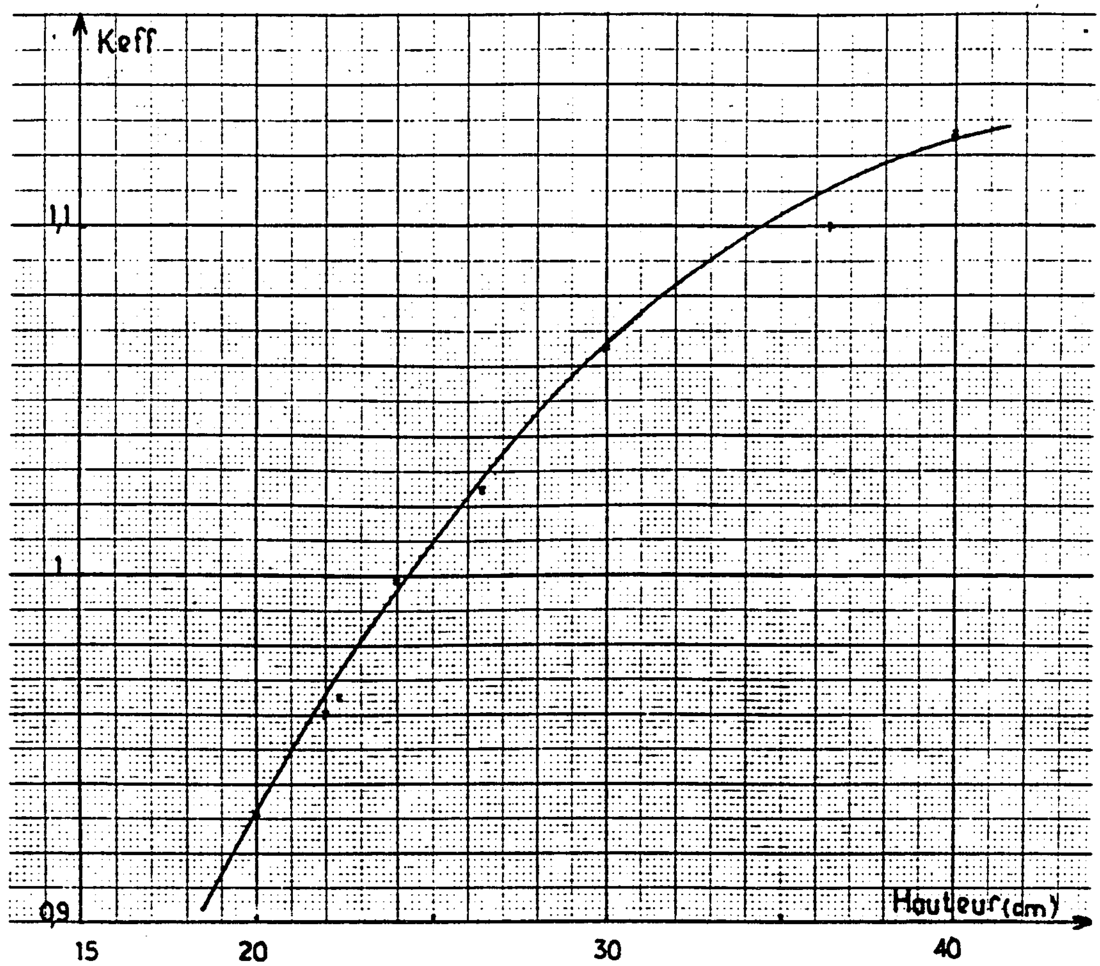
Calibration of reactor energy is obtained by gamma spectrometric analysis of the fissile solution. This radiation-chemical data was obtained in experiments D1-12, D4-195, and LE1.201.

SILENE

EXPERIMENTS RESULTS AT $220 g.l^{-1}$

NUMBER	$C_{U g/l}$	$H_{c\ cm}$	ΔH_{mm}	$H_{f\ cm}$	$V_{f\ l}$	1st PEAK $T_{2\ s}$	$\omega_{s^{-1}}$	$\dot{E}$ fissions $_{s^{-1}}$	E_{p_1}	E_{p_2}	ΔP_{bar}	$\Delta k_{1\ PCM}$	$\Delta k_{1\ \$}$	TEMPERATURE MOYENNE TC1 ET TC2 $\Theta_{i\ °C}$	$\Delta\Theta_{°C\ max}$	$\Delta k_{p\ pcm}$	$\Delta k_{p\ \$}$	DURATION	$N_{f\ fissions}$	NEUTRO SOURC
D4-195	218	23.25	2.4	23.59	22.88	6.5	0.107	$5.5\ 10^{14}$	$2.3\ 10^{16}$			352	0.413	18.8	12.8	352	0.413	700	$4.2\ 10^{16}$	OUI
S1-196	218	23.28	5.6	23.84	23.13	0.30	2.31	$8.2\ 10^{15}$	$2.0\ 10^{16}$	$2.5\ 10^{16}$		762	0.893	18.8	24.8	762	0.893	260	$8.1\ 10^{16}$	NON
S2-196	218	23.28	7.7	24.05	23.33	0.0043	161	$1.0\ 10^{18}$	$3.1\ 10^{16}$	$3.4\ 10^{16}$		1069	1.25	18.8	33.0	1069	1.25	160	$1.1\ 10^{17}$	NON
S1-197	218	23.28	8.4	24.12	23.40	0.0024	289	$2.9\ 10^{18}$	$4.1\ 10^{16}$	$4.6\ 10^{16}$	0.16	1238	1.45	18.8	33.2	1238	1.45	160	$1.2\ 10^{17}$	NON
S1-198	218	23.28	9.5	24.23	23.51	0.00171	405	$6.6\ 10^{18}$	$5.4\ 10^{16}$	$5.6\ 10^{16}$	1.1	1391	1.63	18.9	36.1	1391	1.63	160	$1.2\ 10^{17}$	NON
LE 1-199	218	23.25	15.0	24.75	24.01	0.018	38.5	$3.5\ 10^{17}$	$2.8\ 10^{16}$	$3.1\ 10^{16}$		902	1.06	17.9	60.3	2025	2.37	310	$2.2\ 10^{17}$	OUI
LE 1-201	218	23.25	19.1	25.16	24.40	0.010	69.3	$3.0\ 10^{17}$	$2.6\ 10^{16}$	$3.0\ 10^{16}$		937	1.10	19.1	69.3	2540	2.98	280	$2.5\ 10^{17}$	OUI
LE 1-207	218	23.13	26.8	25.81	25.04									19.1	101	3484	4.08	640	$3.8\ 10^{17}$	OUI
LE 2-207	221	23.13	27.2	25.85	25.07	0.010	69.3	$2.7\ 10^{17}$	$3.0\ 10^{16}$	$3.2\ 10^{16}$		946	1.11	19.0	101	3510	4.11	550	$3.5\ 10^{17}$	OUI
LE 1-208	221	23.20	27.0	25.90	25.12	0.010	69.3	$3.0\ 10^{17}$	$3.2\ 10^{16}$	$3.5\ 10^{16}$		946	1.11	19.0	101	3510	4.11	550	$3.5\ 10^{17}$	OUI

LE 1-207 1,5 2e16 ±12



. SILENE .

Concentration 218 $g.l^{-1}$

Variation du keff en fonction de la hauteur de solution

Résultats MORET

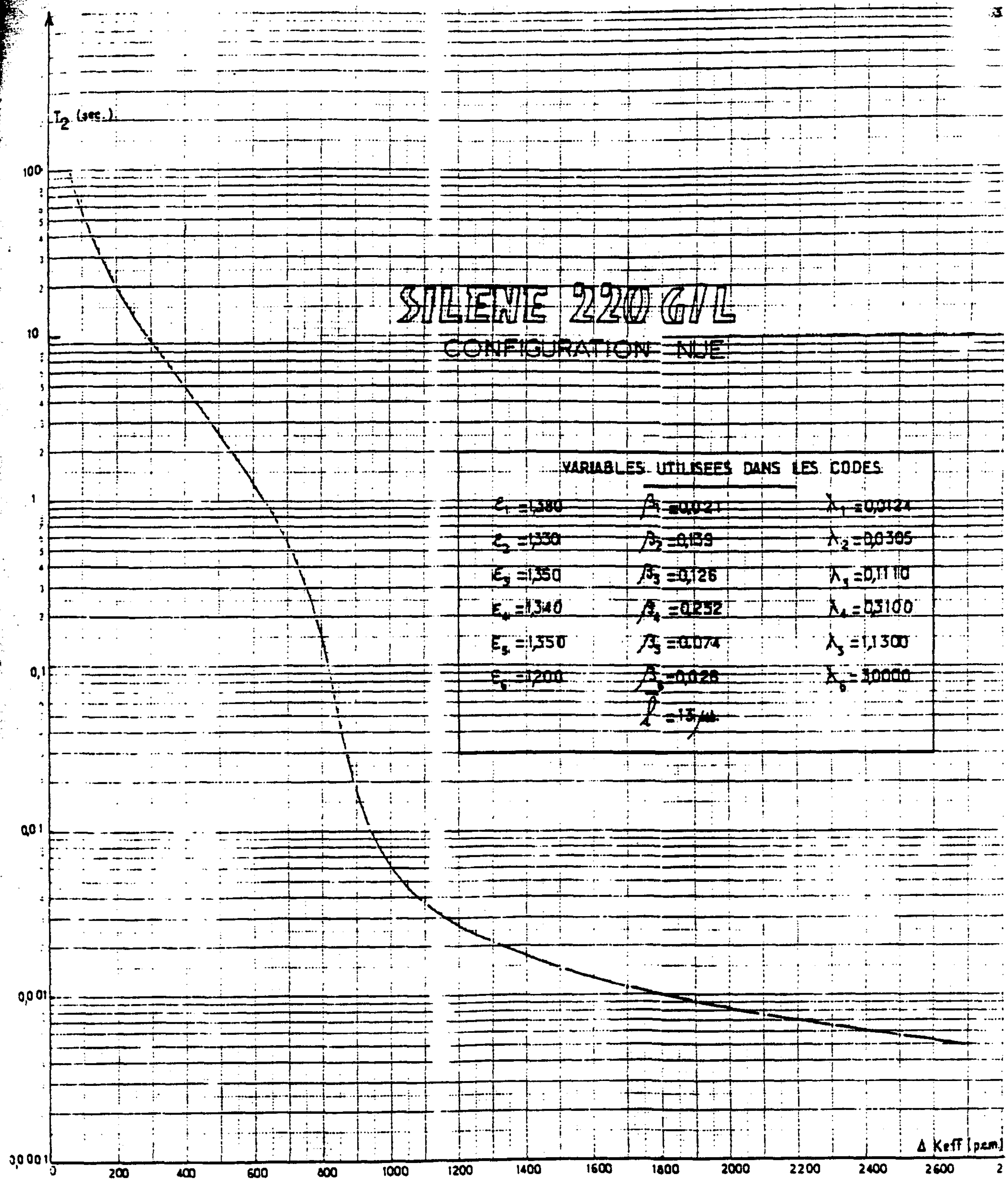
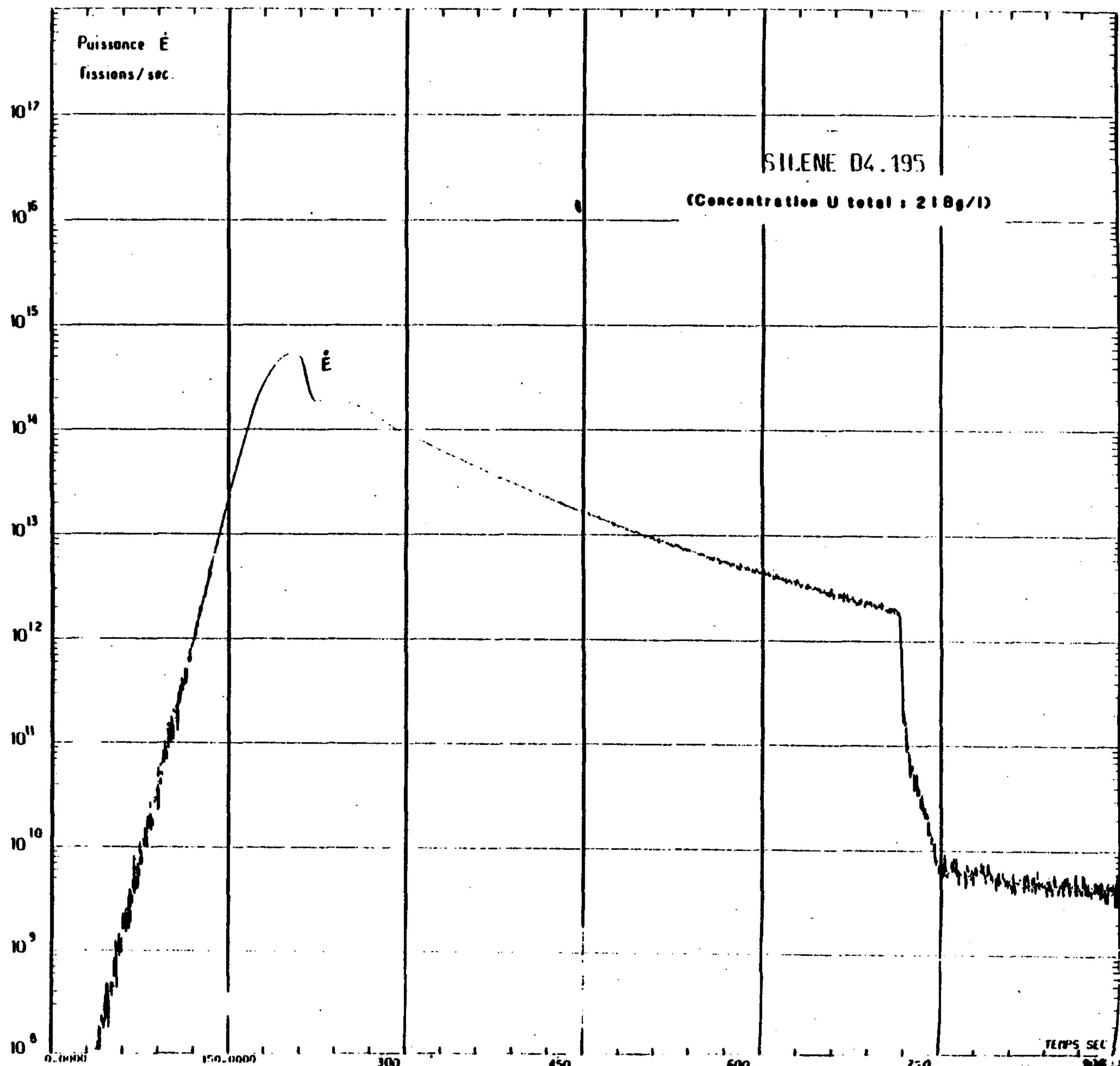
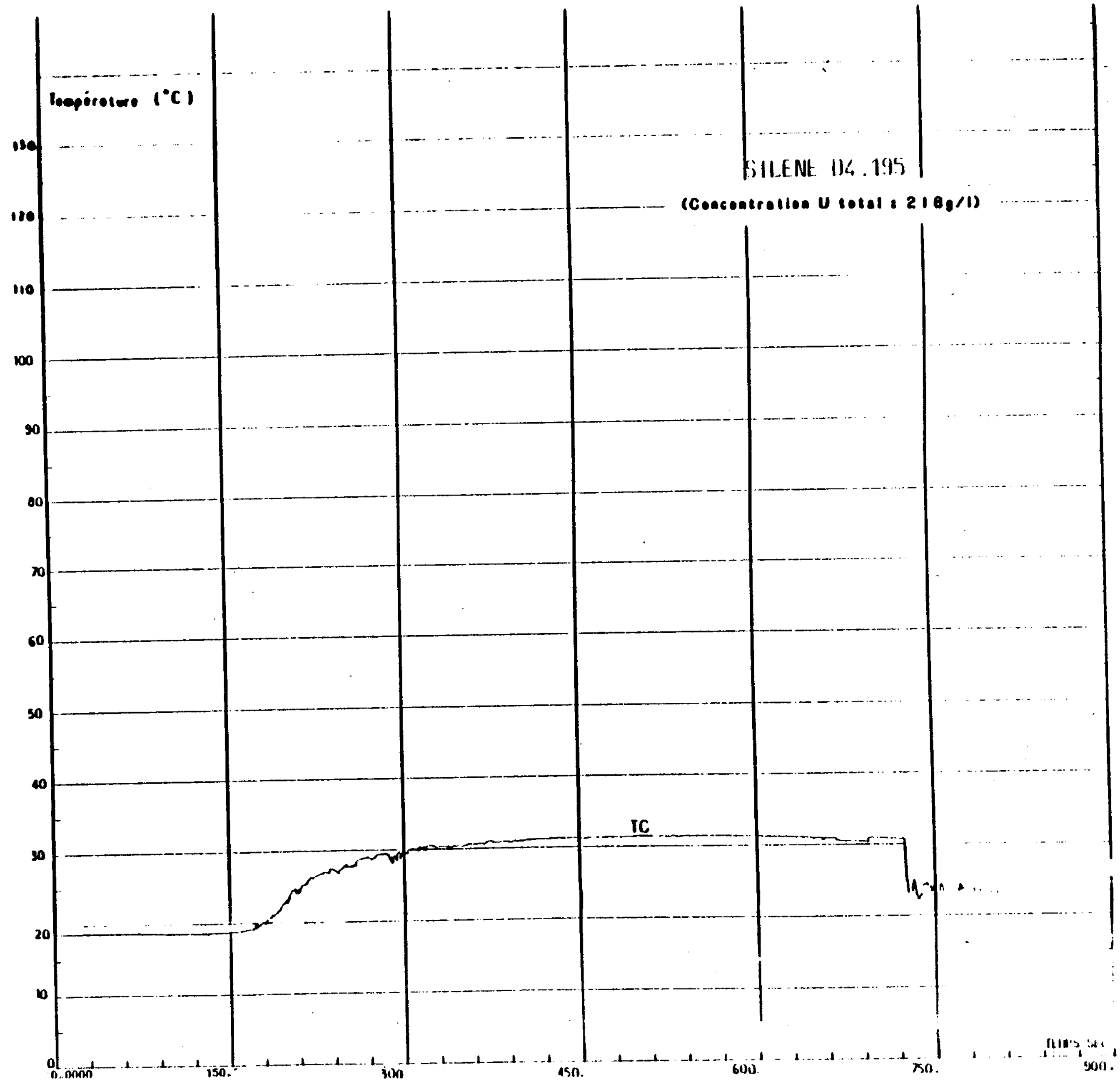


Fig: 2 Relation entre le temps de doublement T2 et la reactivite Δk



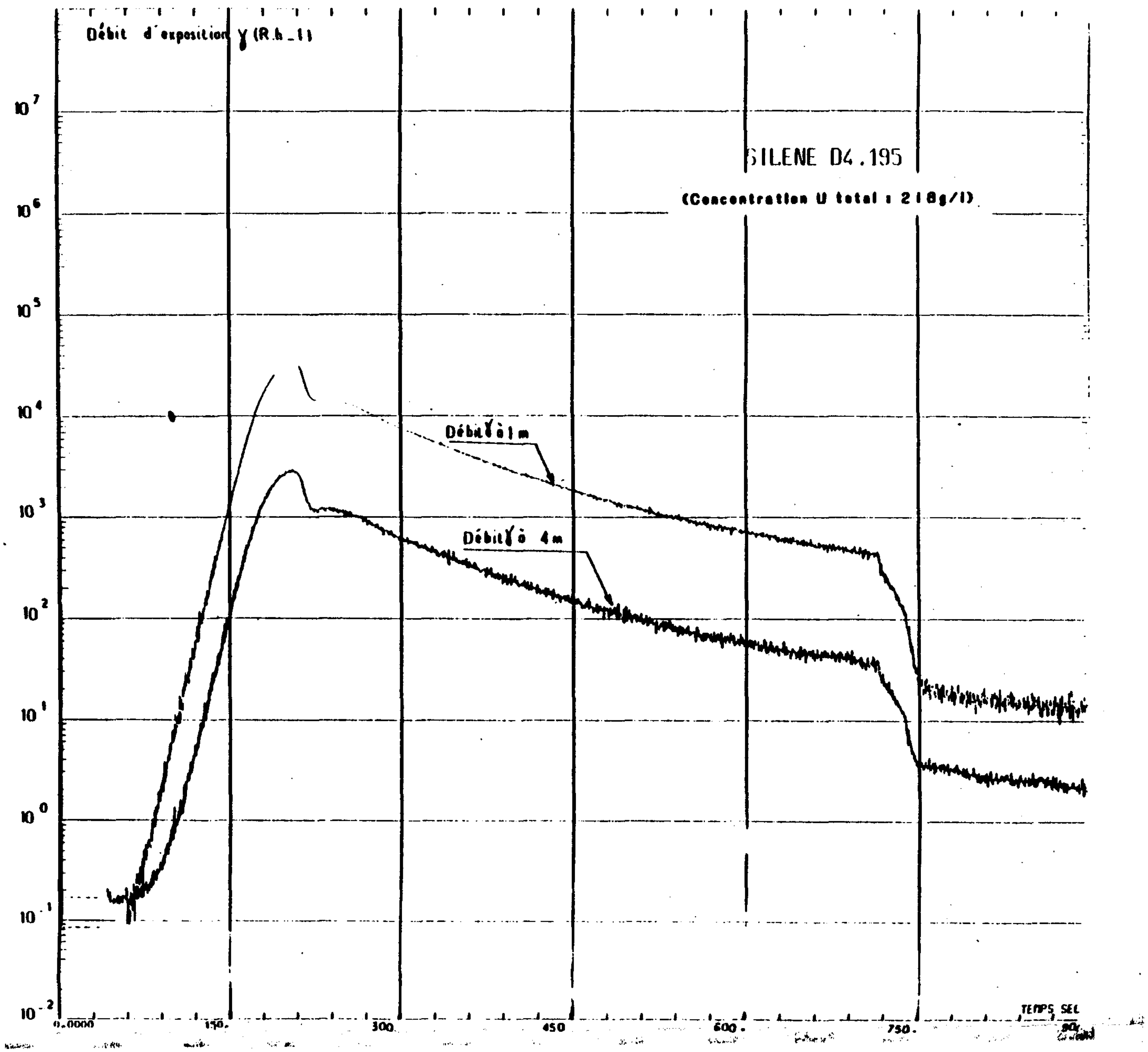
SILENE

Fig: 3 – Expérience du type "Divergence"
Evolution de la puissance



SILENE

Fig. 6 - Expérience du type "Divergence"
Evolution de la température au sein du réacteur



SILENE

Fig: 5 - Expérience du type "Divergence"
Débit d'exposition γ à 1m et 4m
de l'axe du réacteur

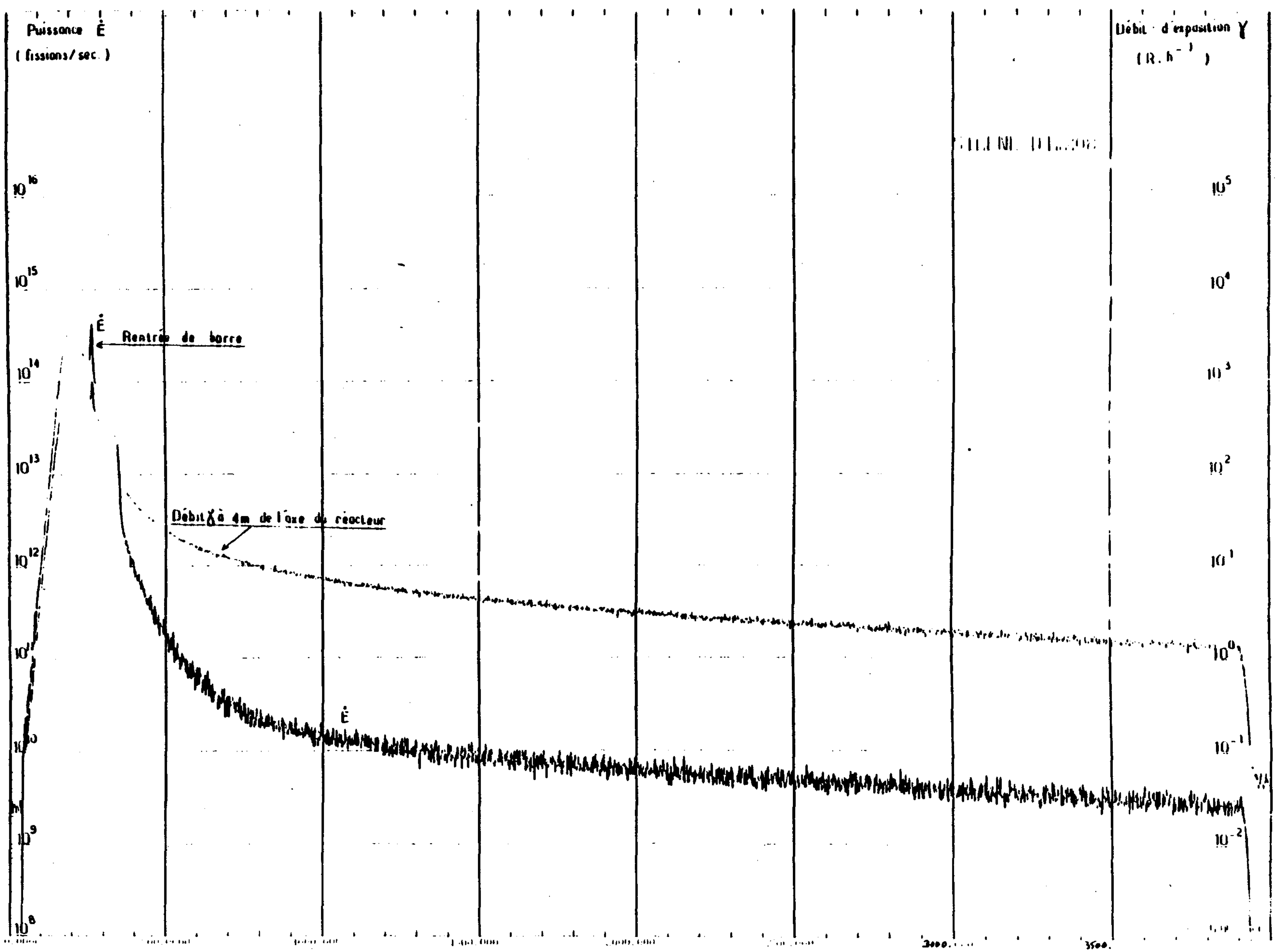
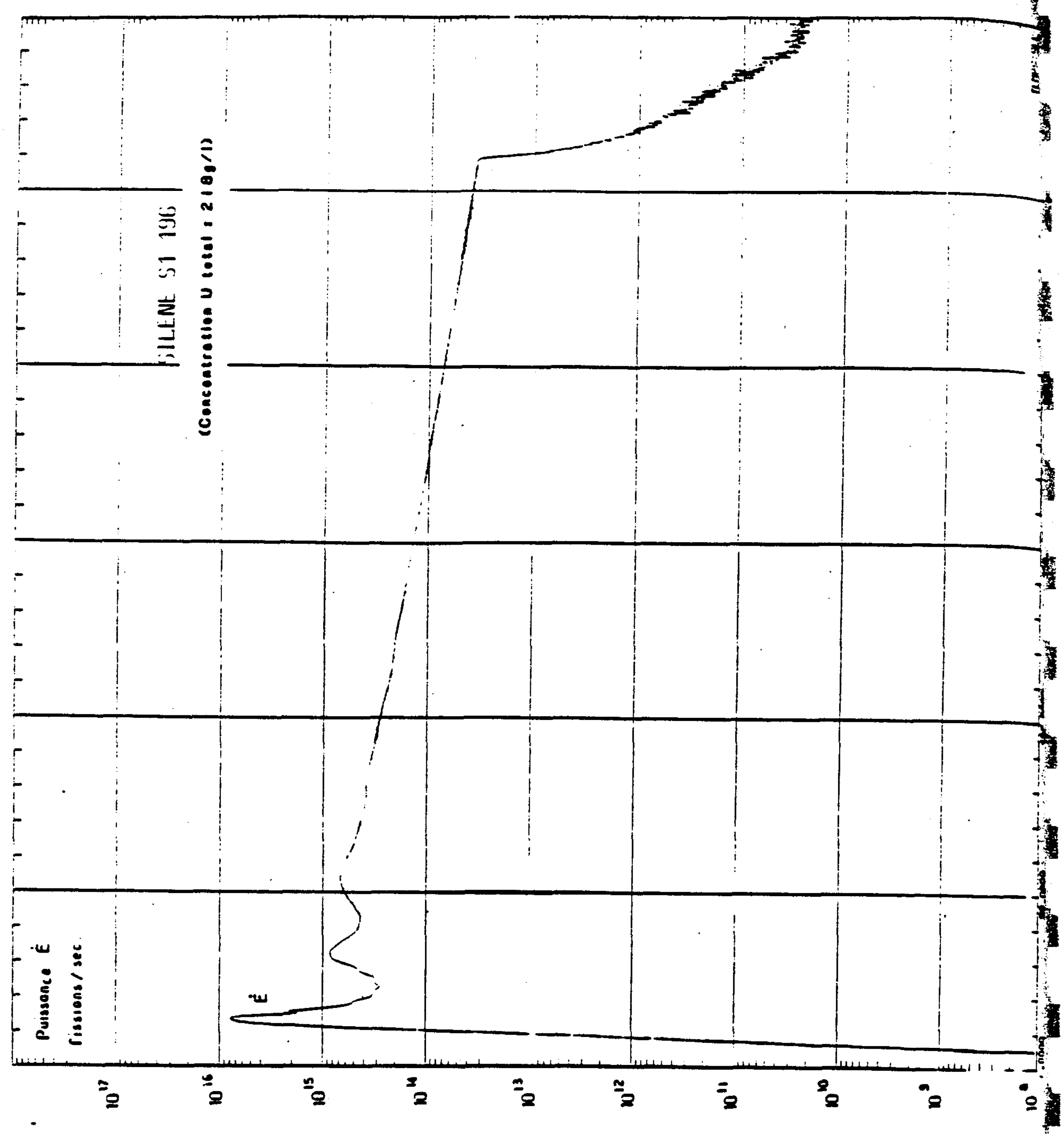
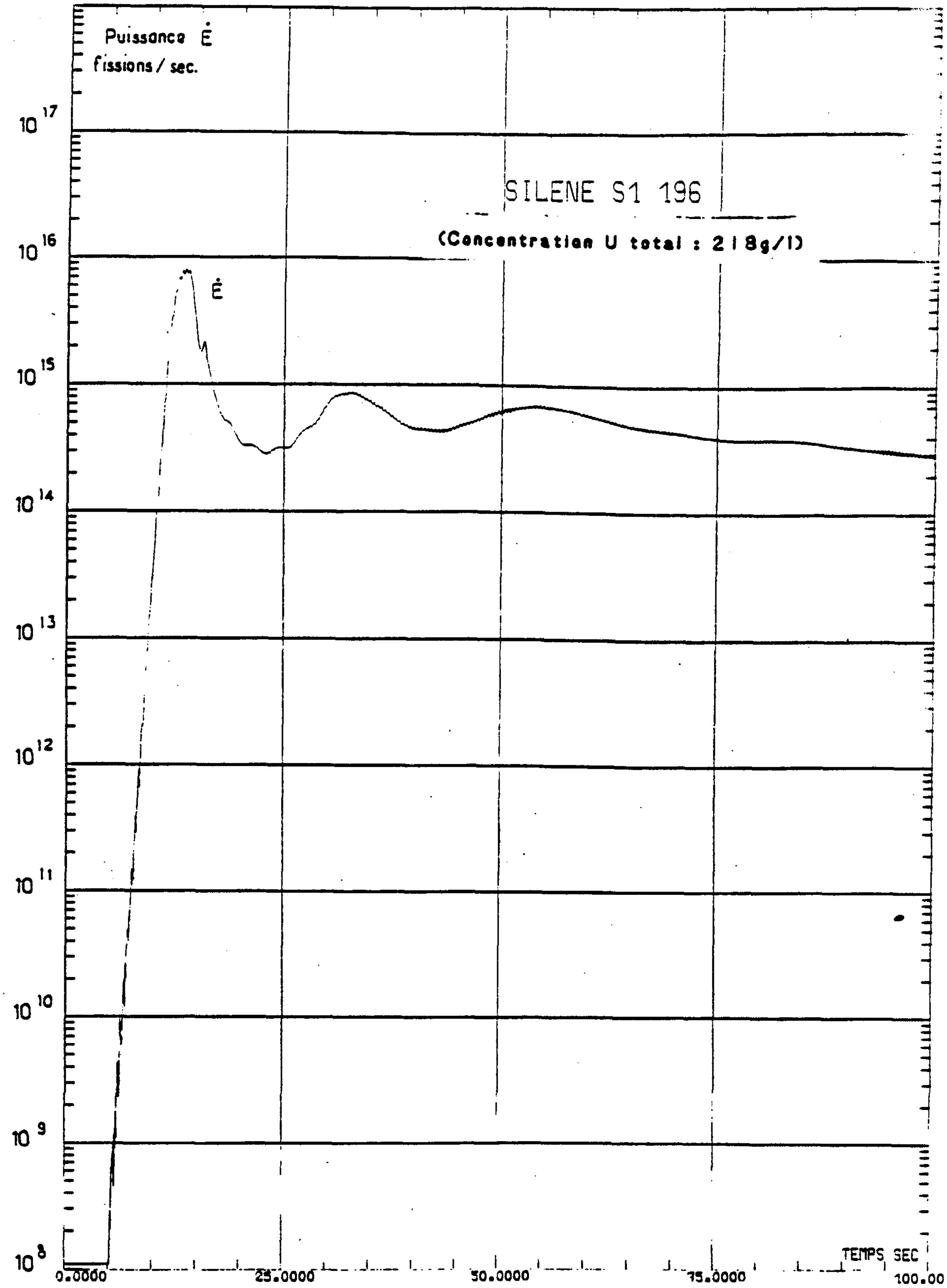


FIG. 6. Evolution de la Puissance et du Débit d'Exposition γ à 4m



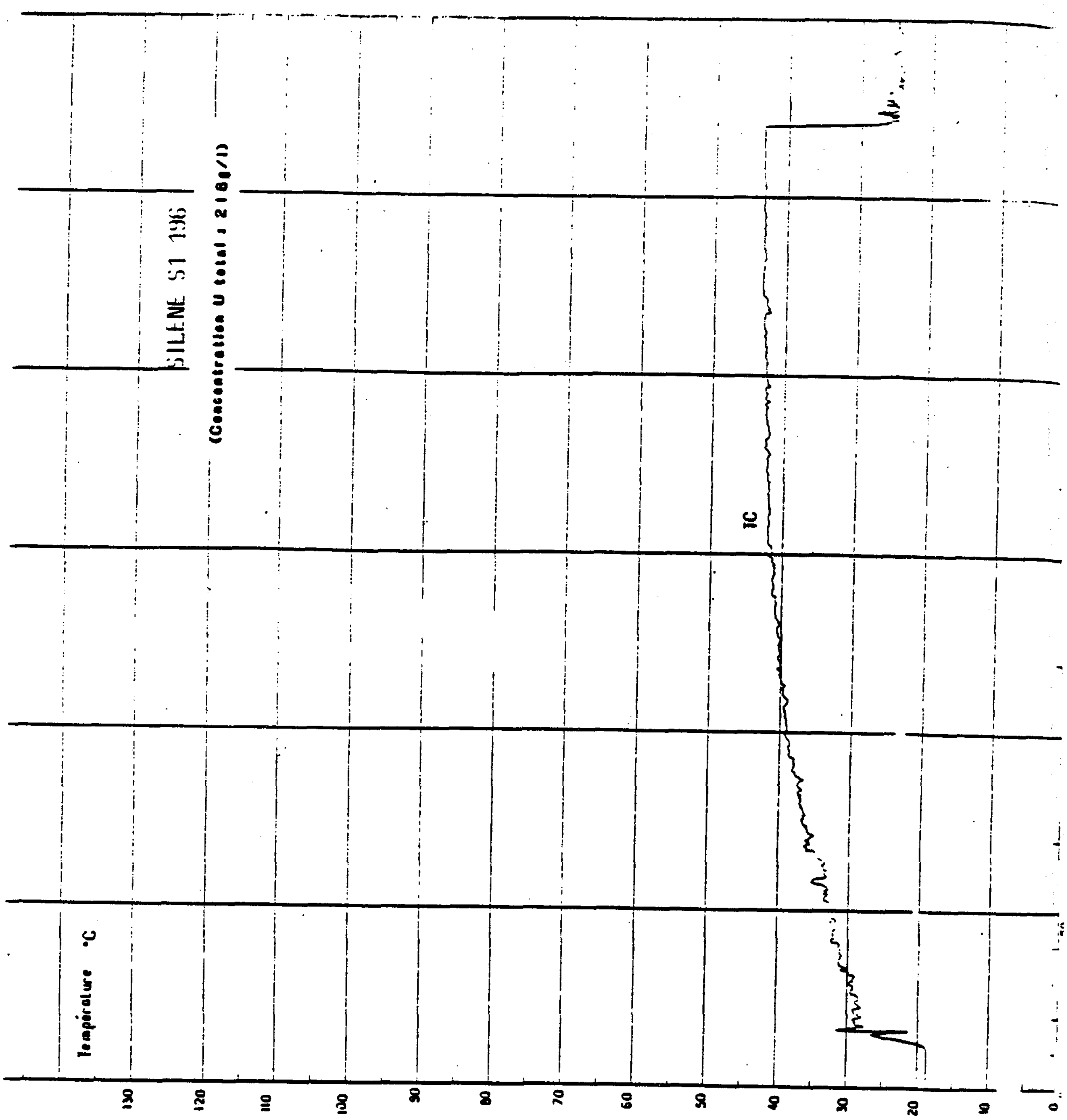
SILENE

Fig: 7 – Expérience du type "Salve"
Evolution de la puissance
(toute l'expérience)



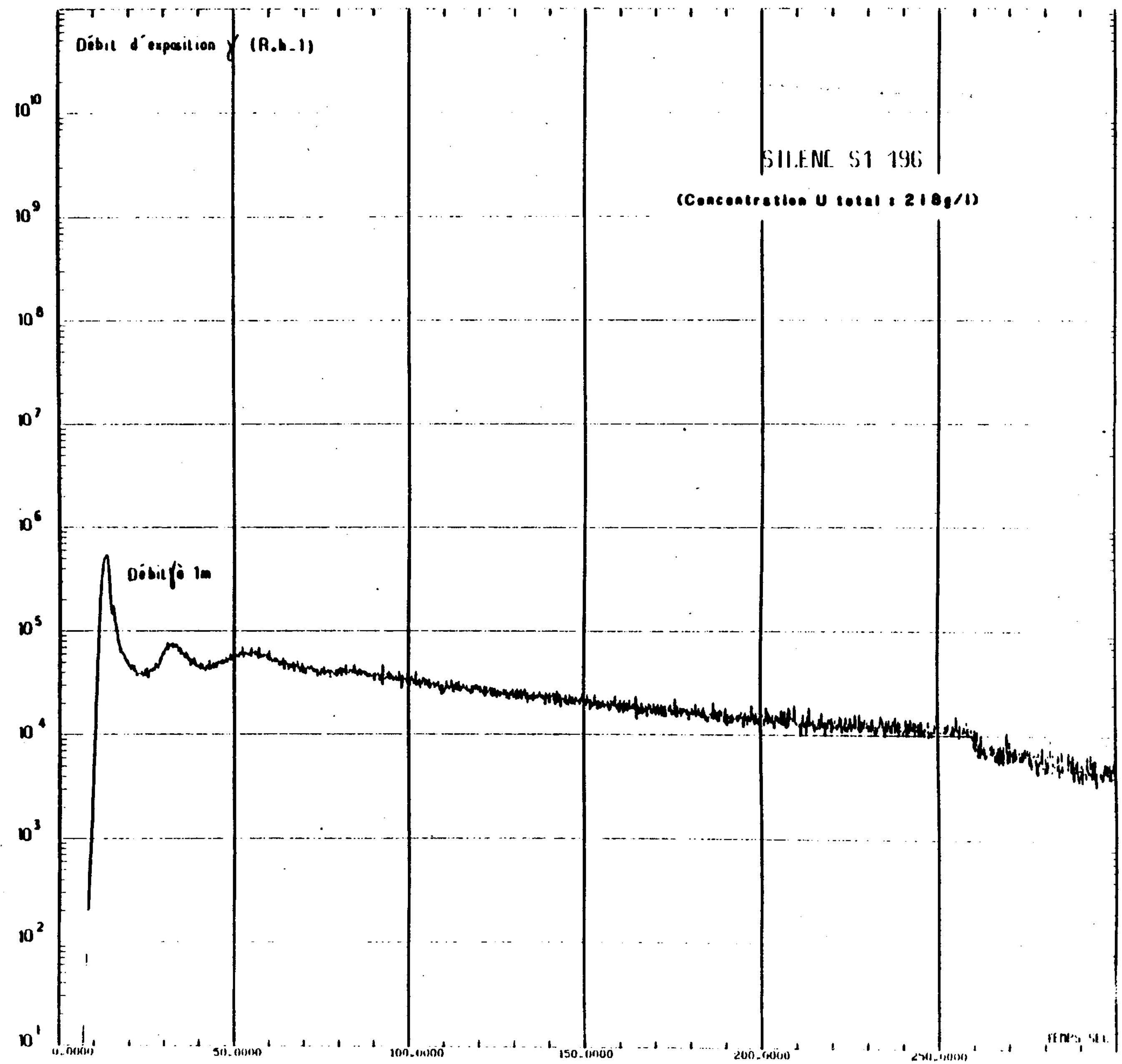
SILENE

Fig: 8 – Expérience du type "Salve"
Evolution de la puissance
(premier pic)



SILENE

Fig: 9 – Expérience du type "Salve"
Evolution de la température au sein du réacteur

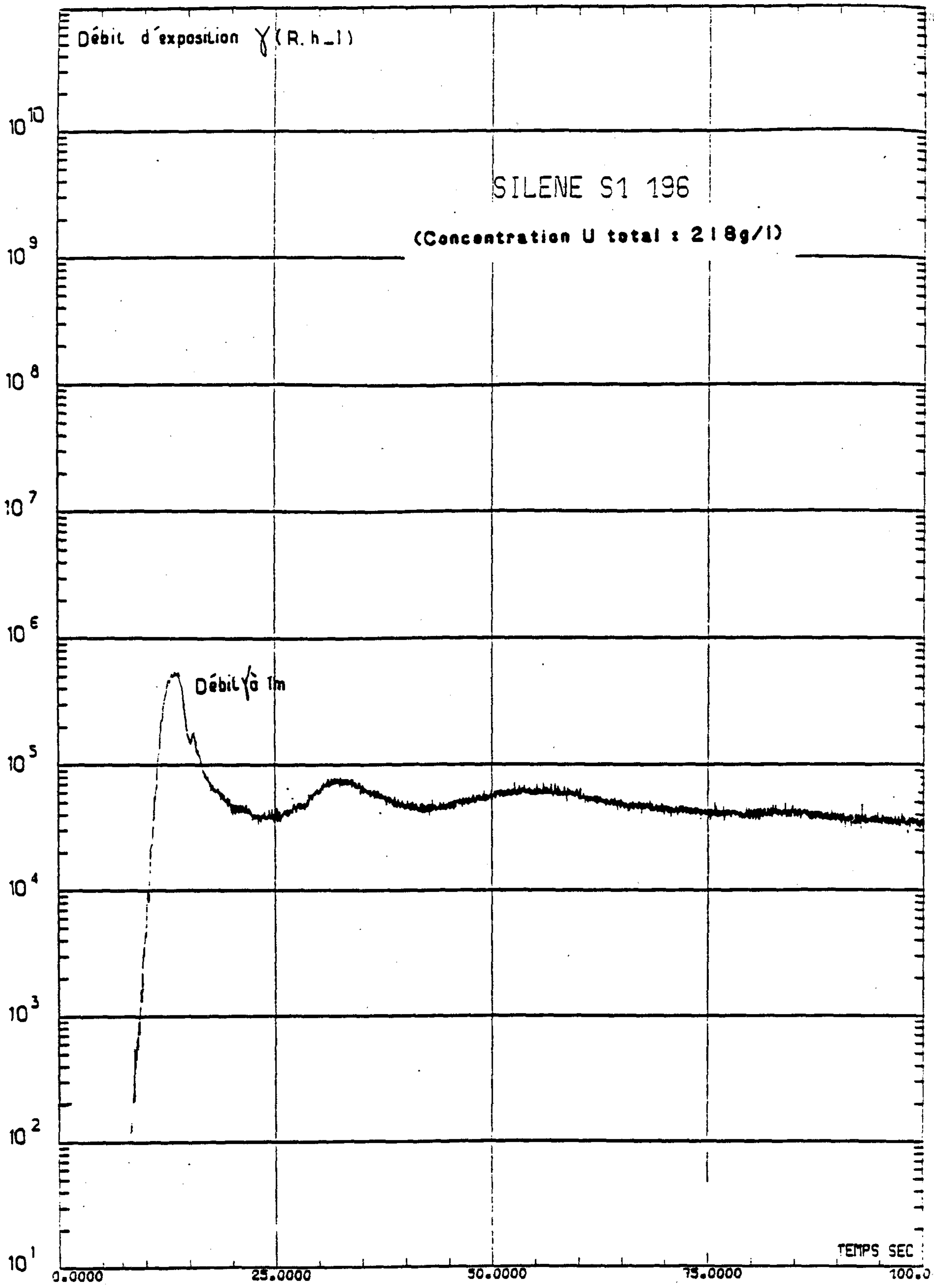


SILENE

Fig: 10 – Expérience du type "Salve"

Débit d'exposition γ à 1m de l'axe du réacteur

(toute l'expérience)

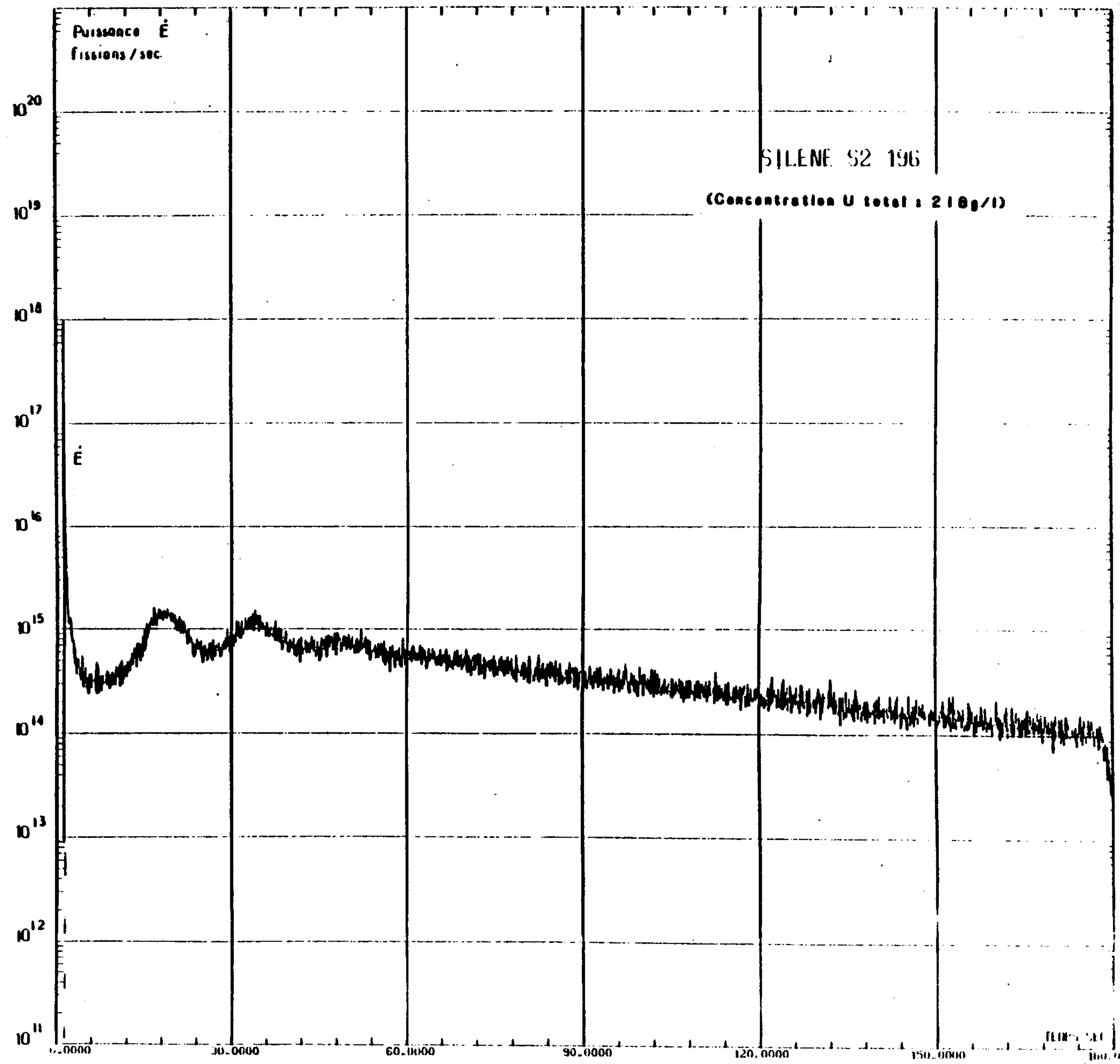


SILENE

Fig: 11 _Expérience du type "Salve"

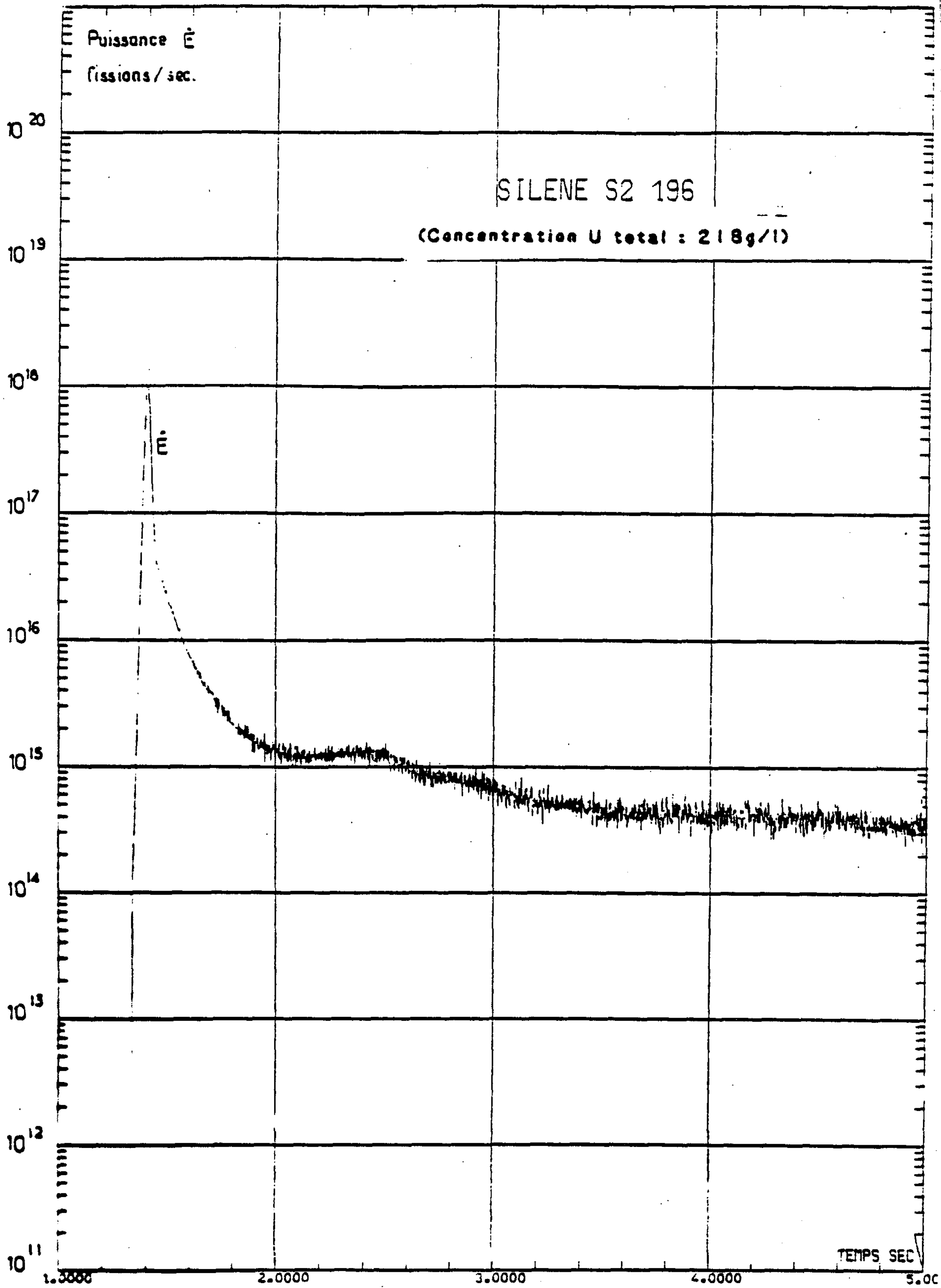
Débit d'exposition γ á 1m de l'axe du réacteur

(premier pic)



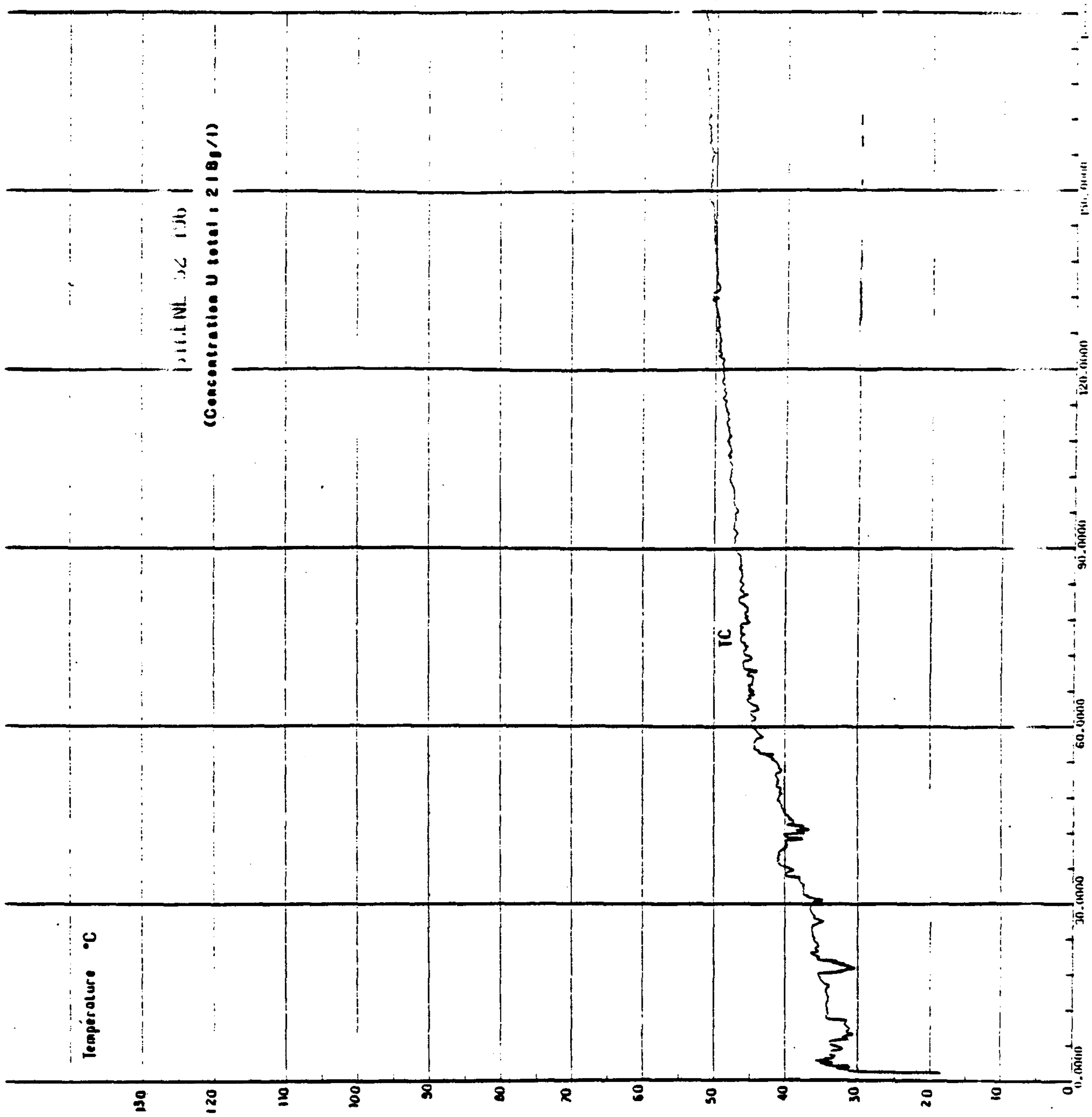
SILENE

Fig: 12 – Expérience du type "Salve"
Evolution de la puissance
(toute l'expérience)



SILENE

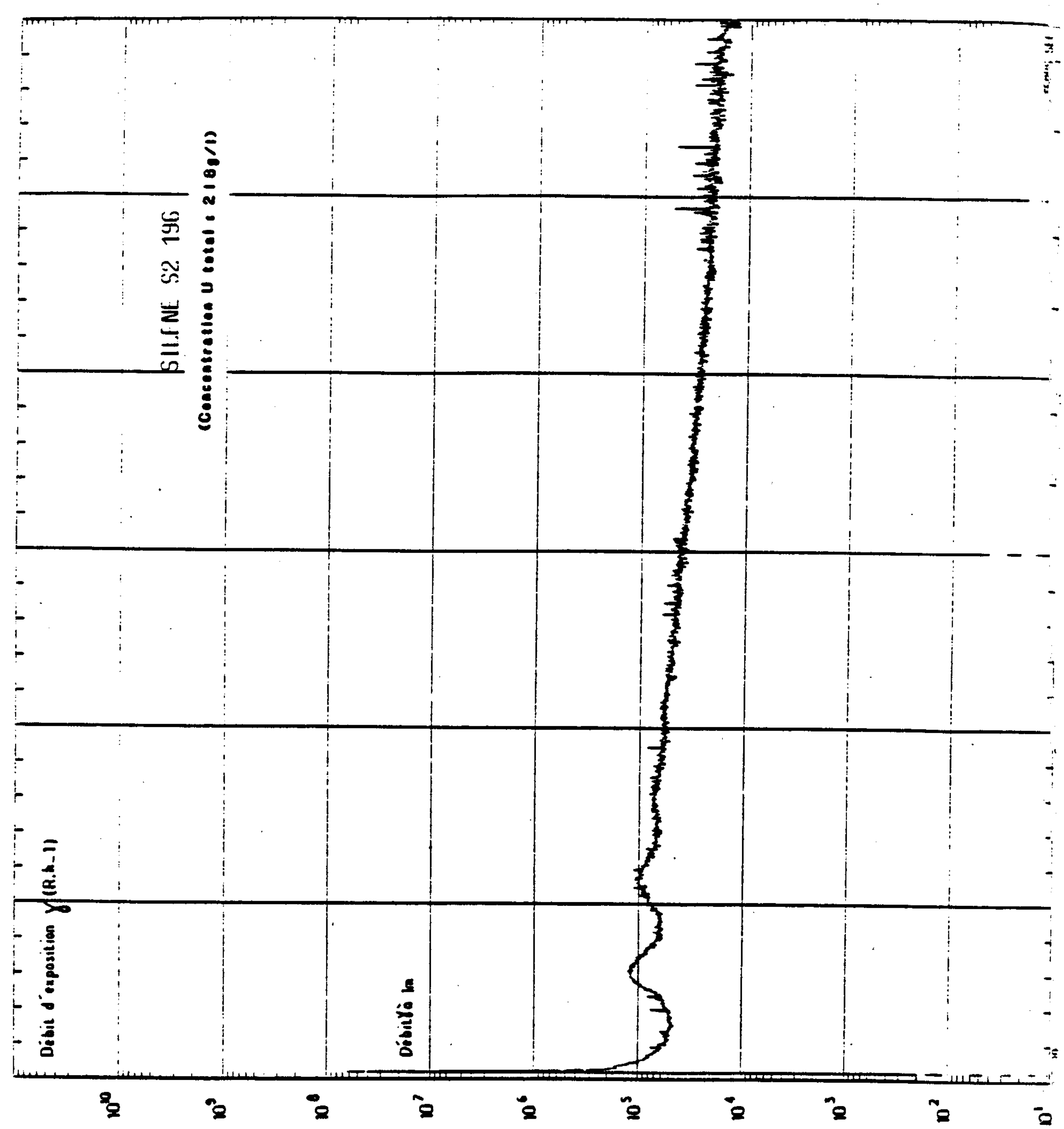
Fig.13 – Expérience du type "Salve"
Evolution de la puissance
(premier pic)



SILENE

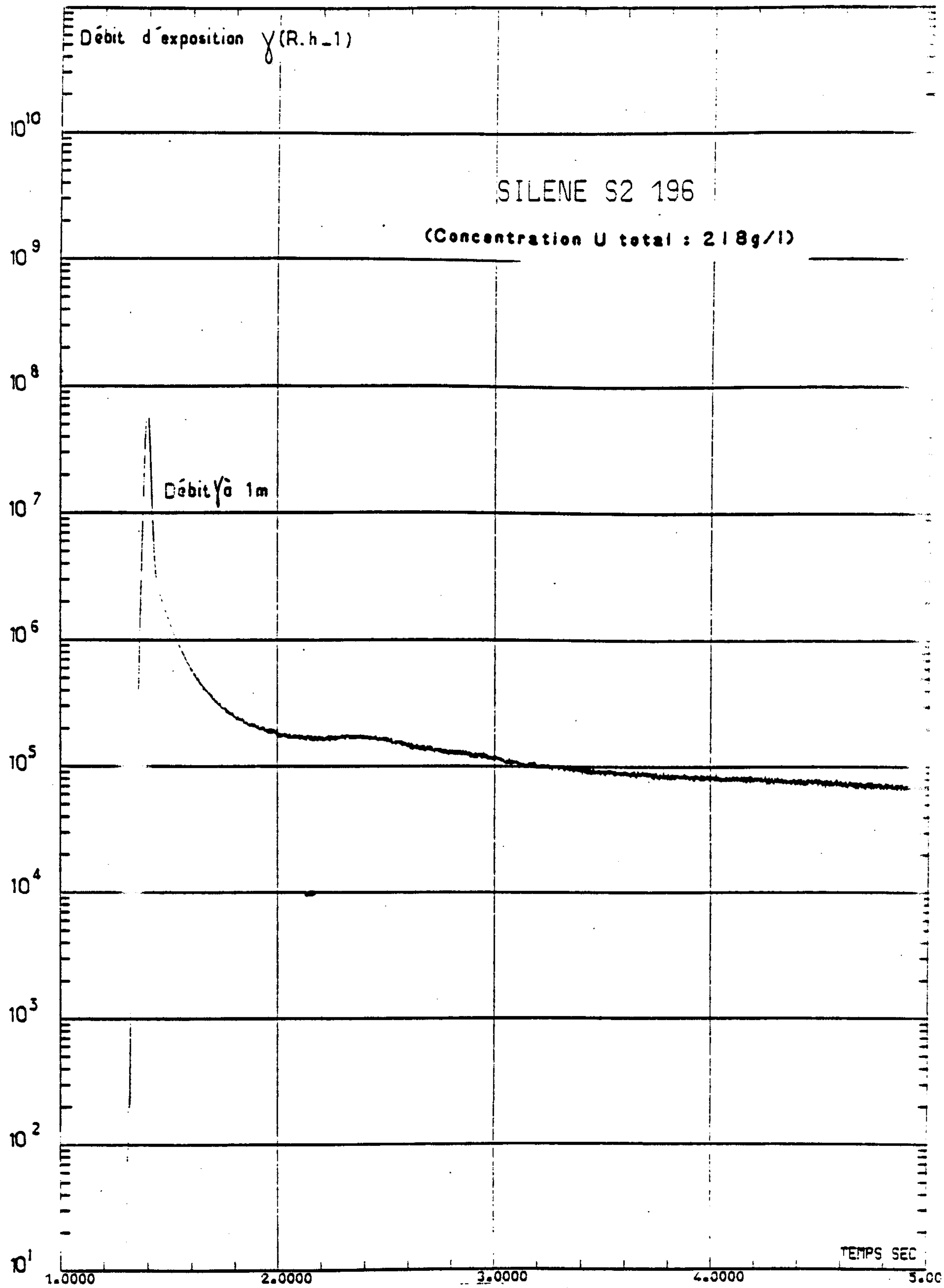
Fig: 14 – Expérience du type "Salve"

Evolution de la température au sein du réacteur



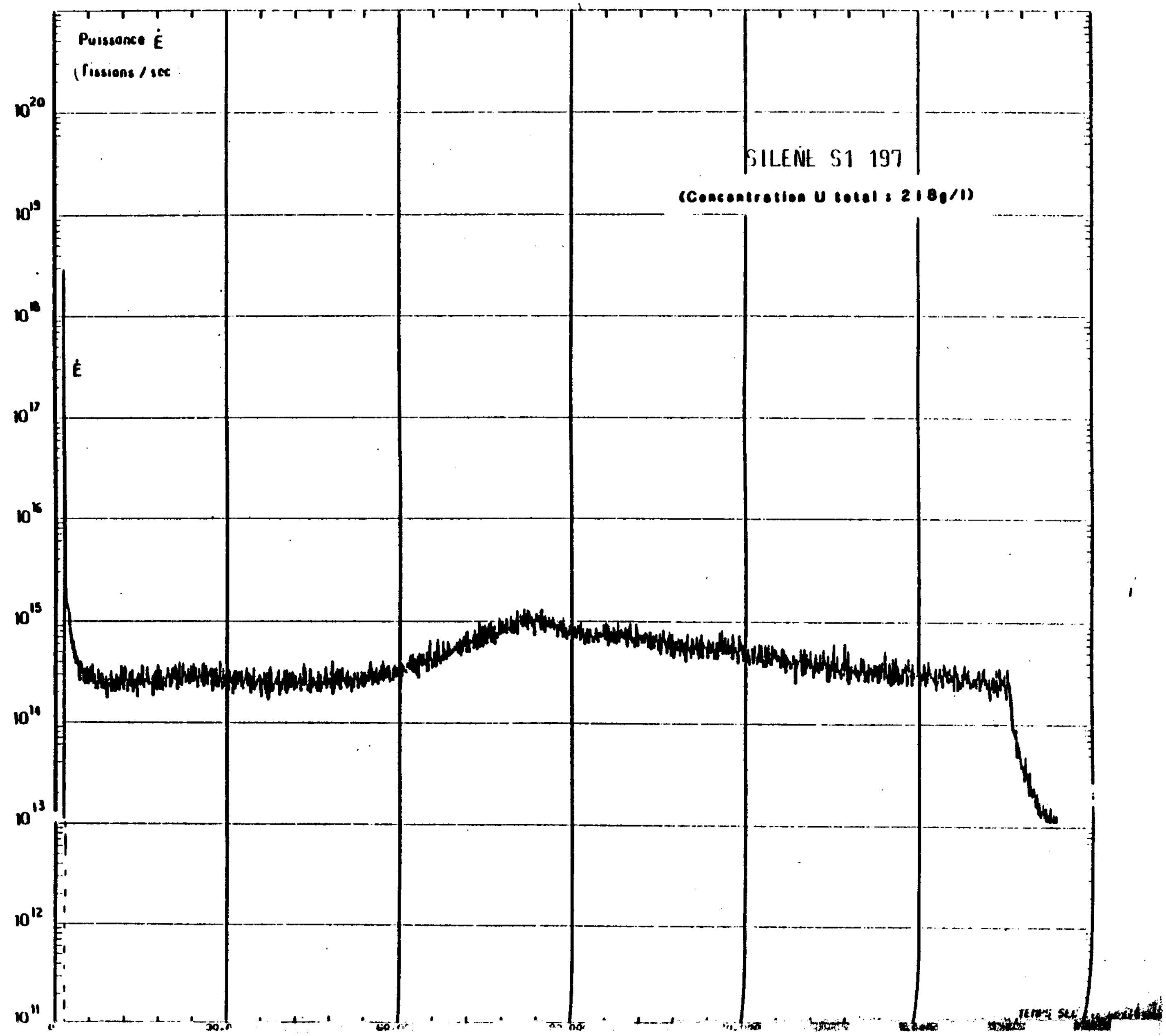
SILENE

Fig: 15 – Expérience du type "Salve"
Débit d'exposition γ á 1m de l'axe du réacteur
(toute l'expérience)



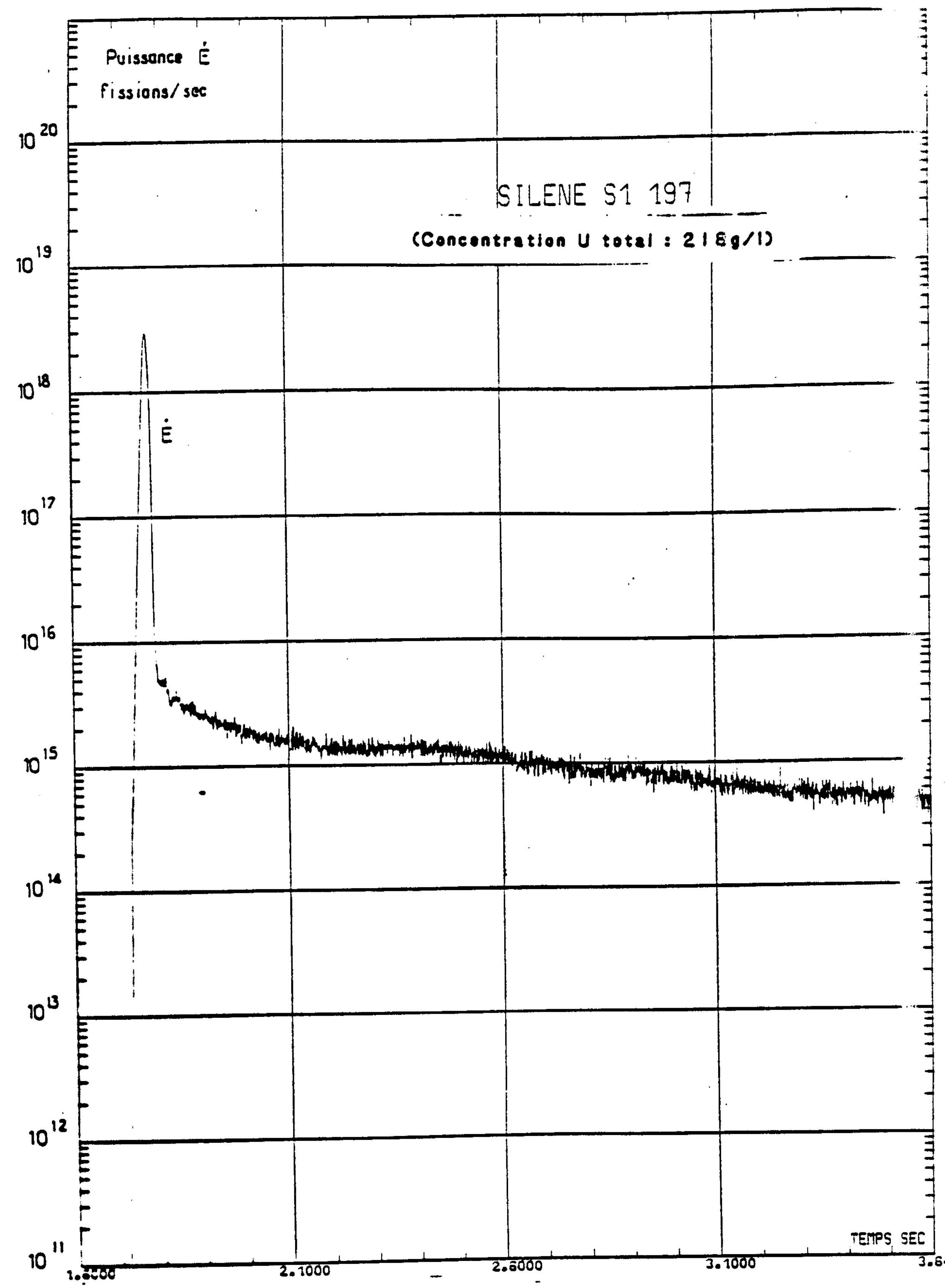
SILENE

Fig: 16 _Expérience du type "Salve"
Débit d'exposition γ à 1m de l'axe du réacteur
(premier pic)



SILENE

Fig: 17 – Expérience du type "Salve"
Evolution de la puissance
(toute l'expérience)



SILENE

Fig: 18 – Expérience du type "Salve"
Evolution de la puissance
(premier pic)

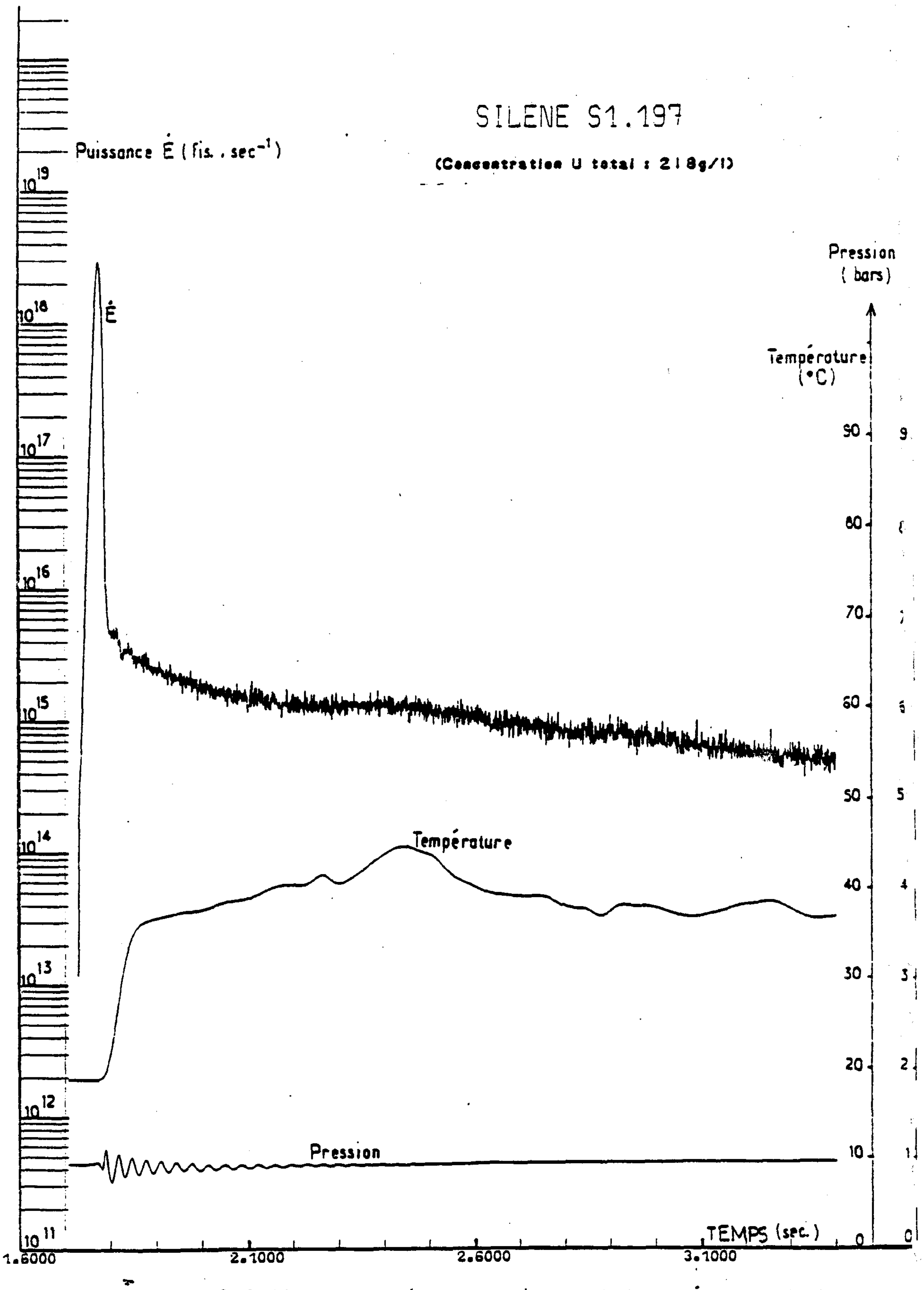


FIG.19 _ SILENE_(218g/l) . Evolution de la puissance , de la température , de la pression au sein du reacteur

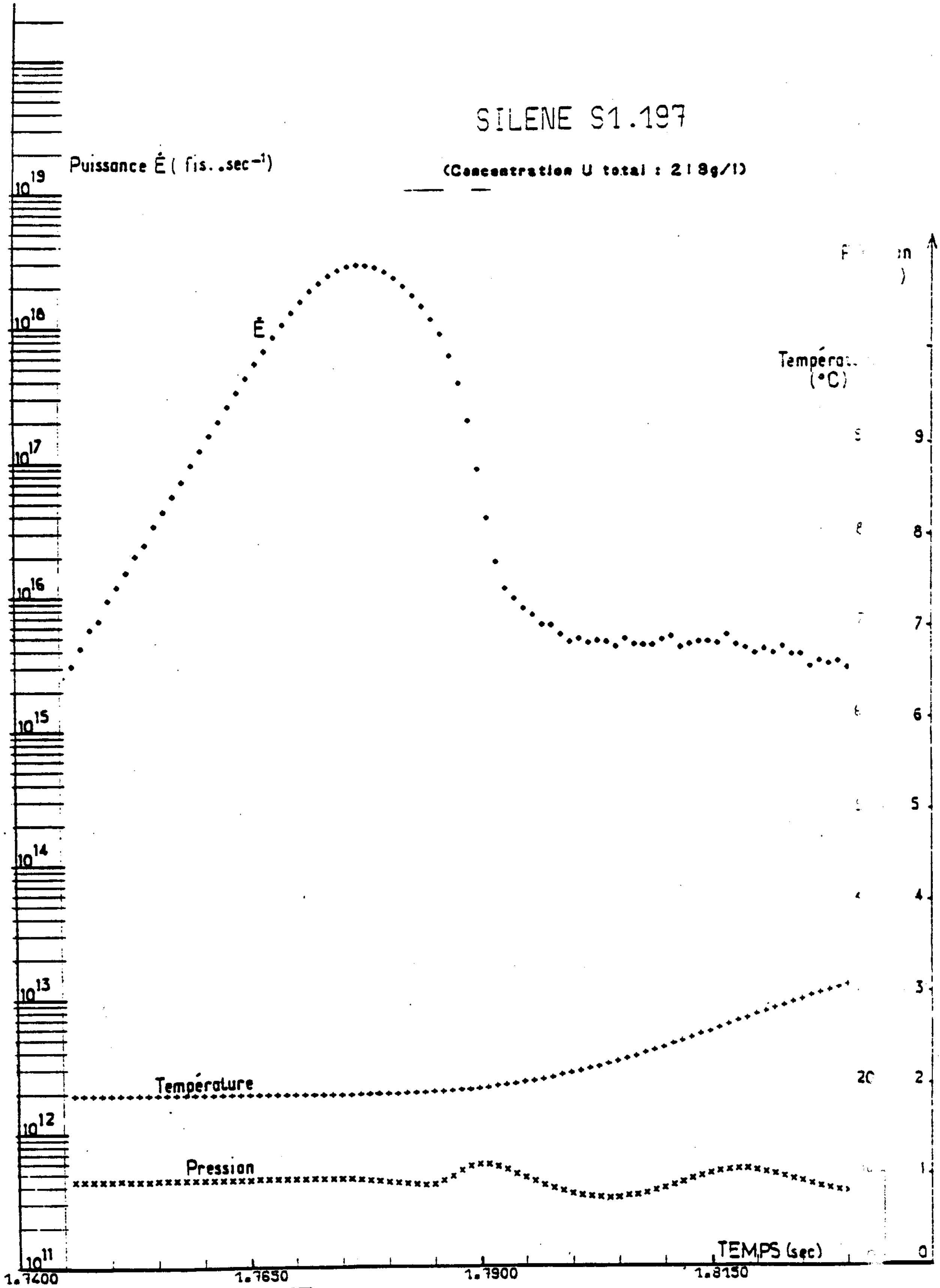
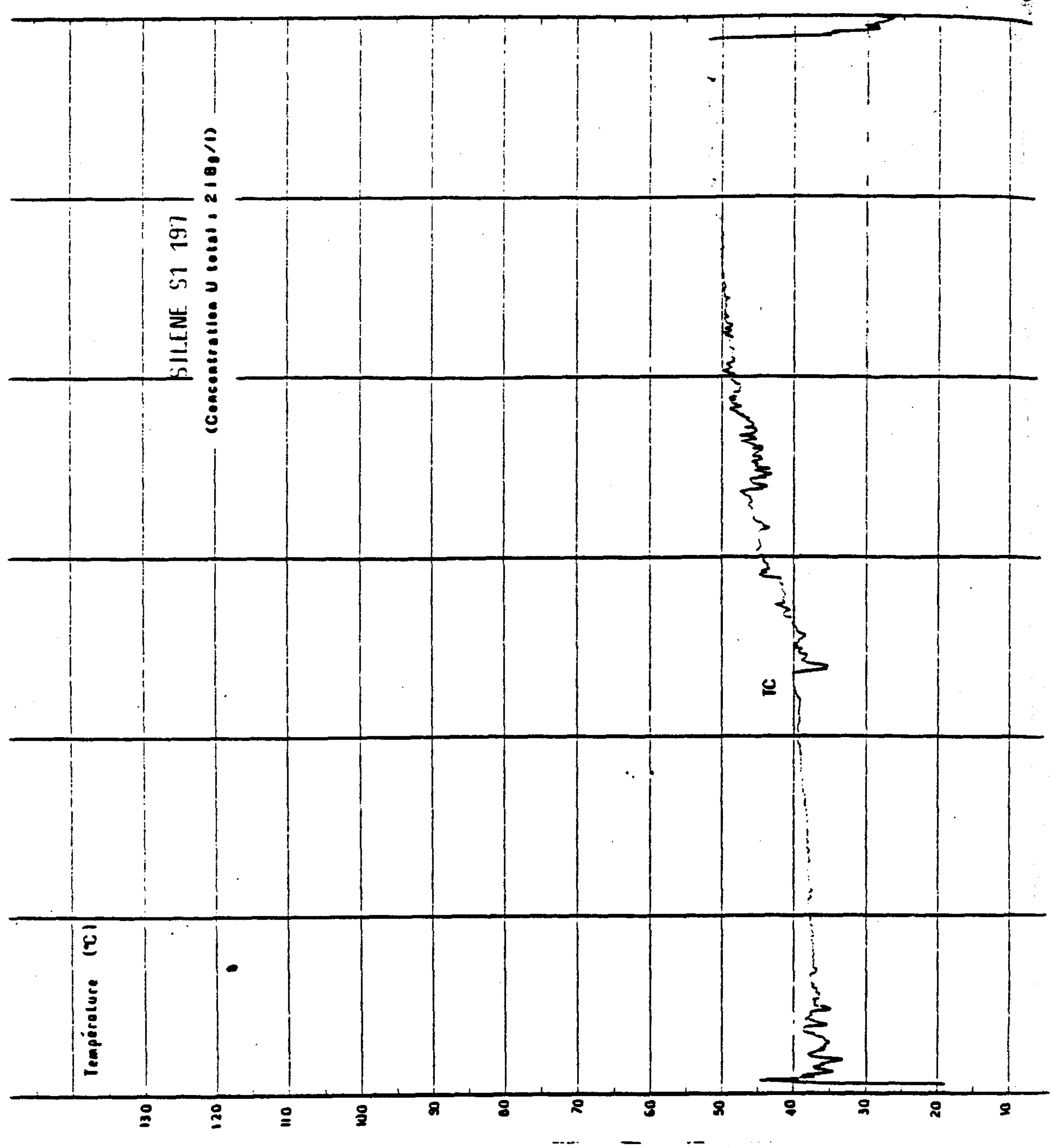


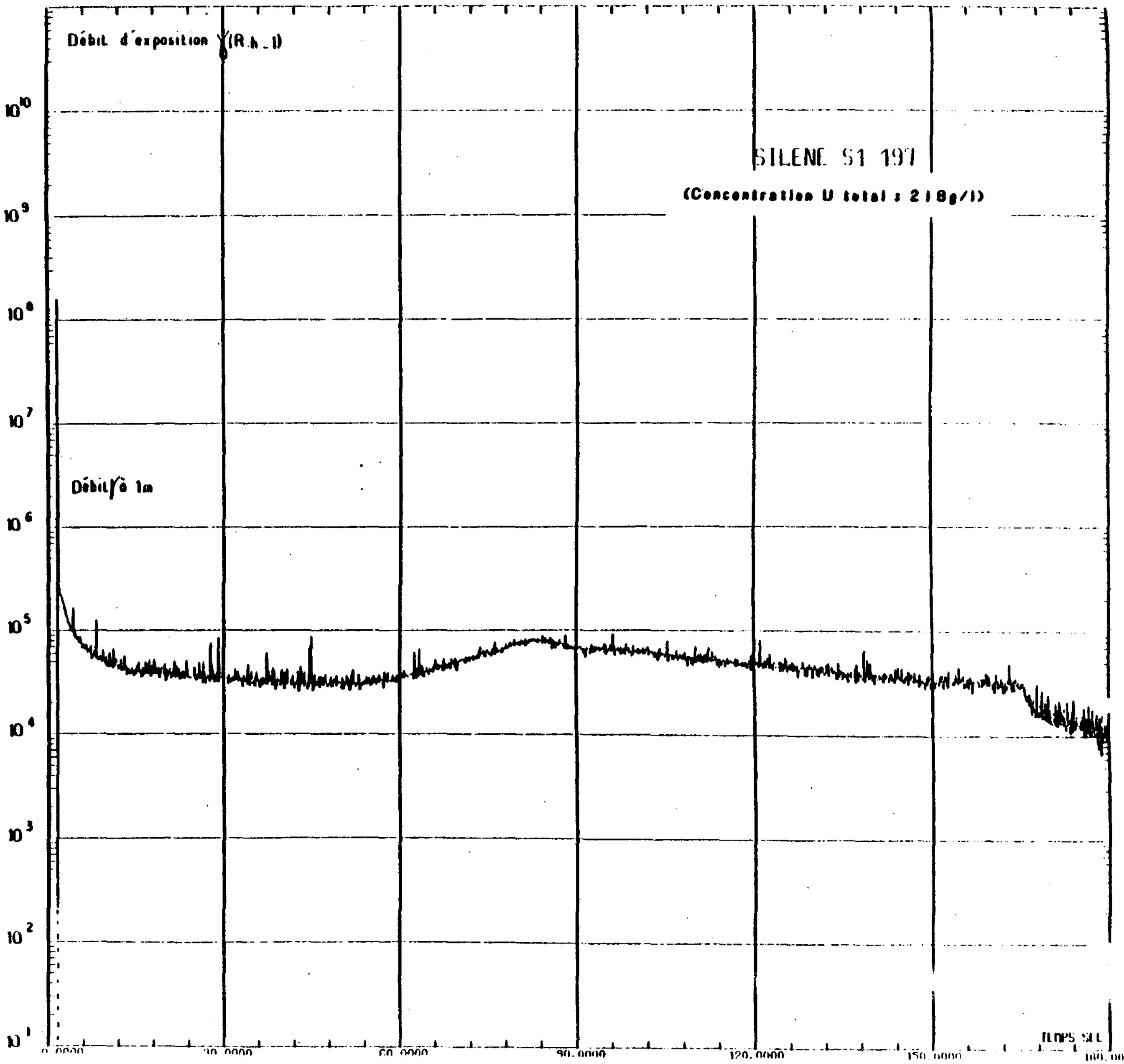
FIG 20 _ SILENE _ (218g/l) Evolution de la puissance , de la température , de la pression au sein du reacteur (détail)



SILENE

Fig: 21 – Expérience du type "Salve"

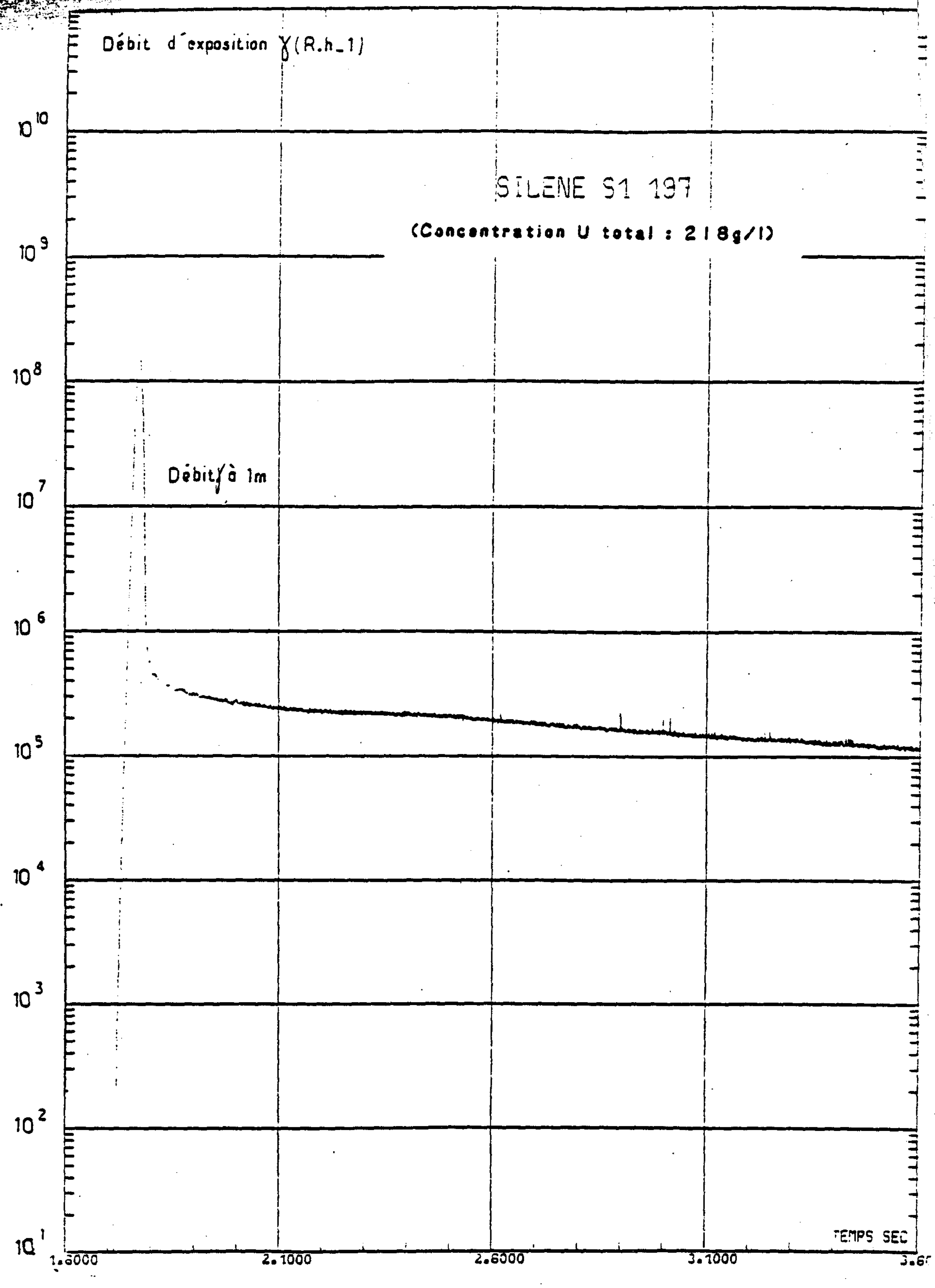
Evolution de la température au sein du réacteur



SILENE

Fig: 22 – Expérience du type "Salve"

Debit d'exposition γ á 1m de l'axe du réacteur (toute l'expérience)



SILENE

Fig: 23 – Expérience du type "Salve"
Debit d'exposition γ á 1m de l'axe du réacteur
(premier pic)

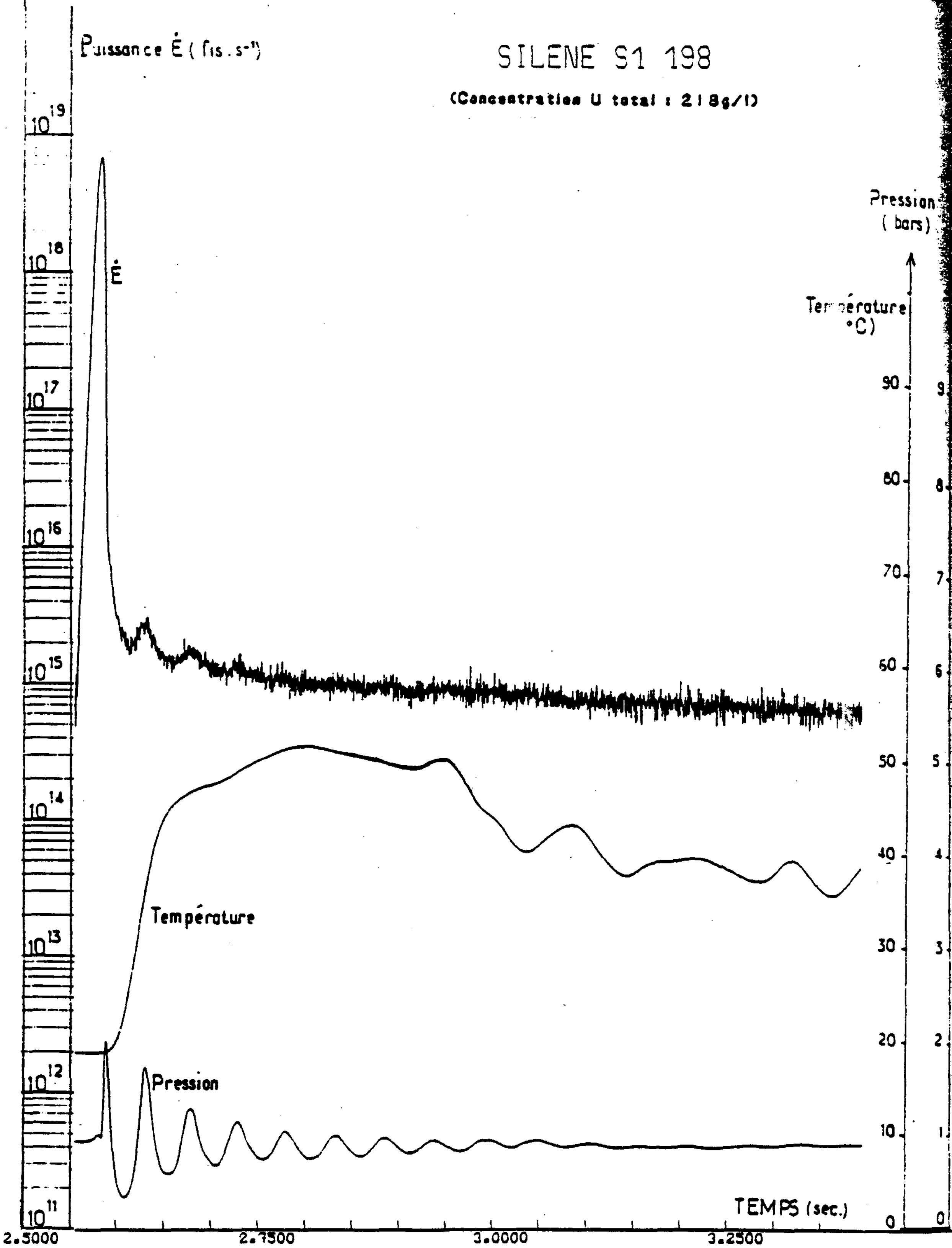
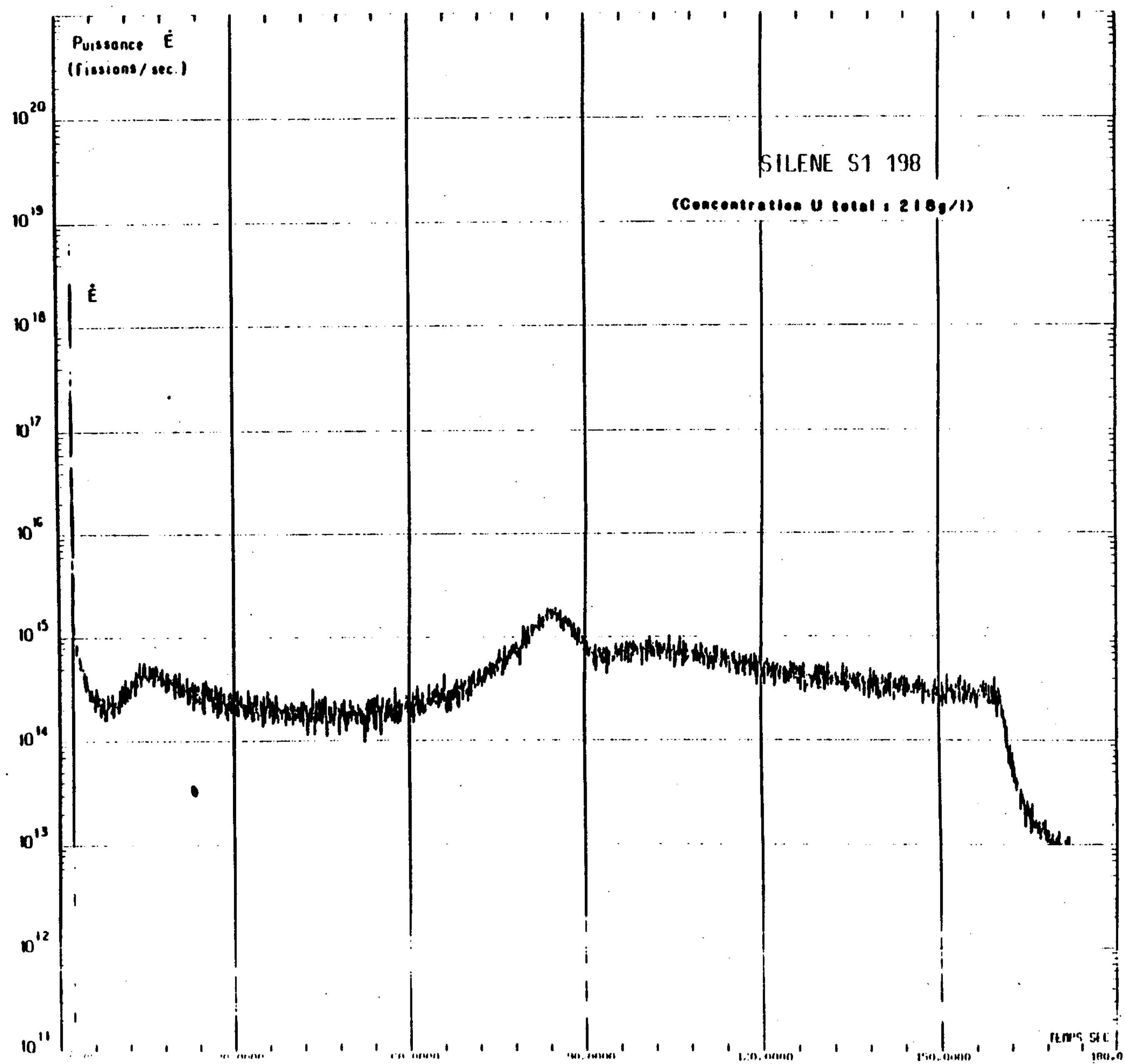


FIG.25 _ SILENE _ (218g/l) . Evolution de la puissance , de la température , de la pression au sein du réacteur

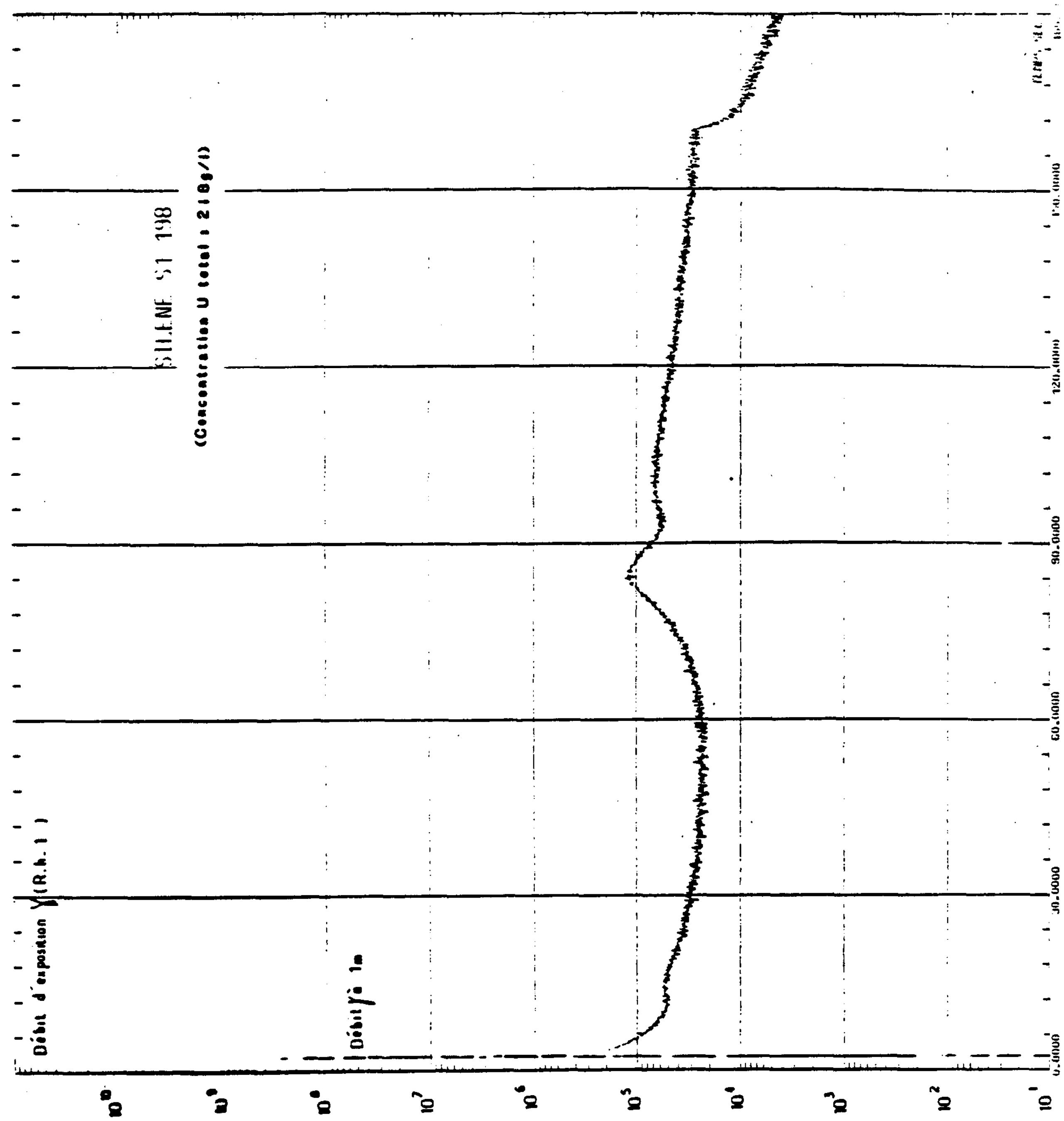


SILENE

Fig: 24 – Expérience du type "Salve"

Evolution de la puissance

(toute l'expérience)

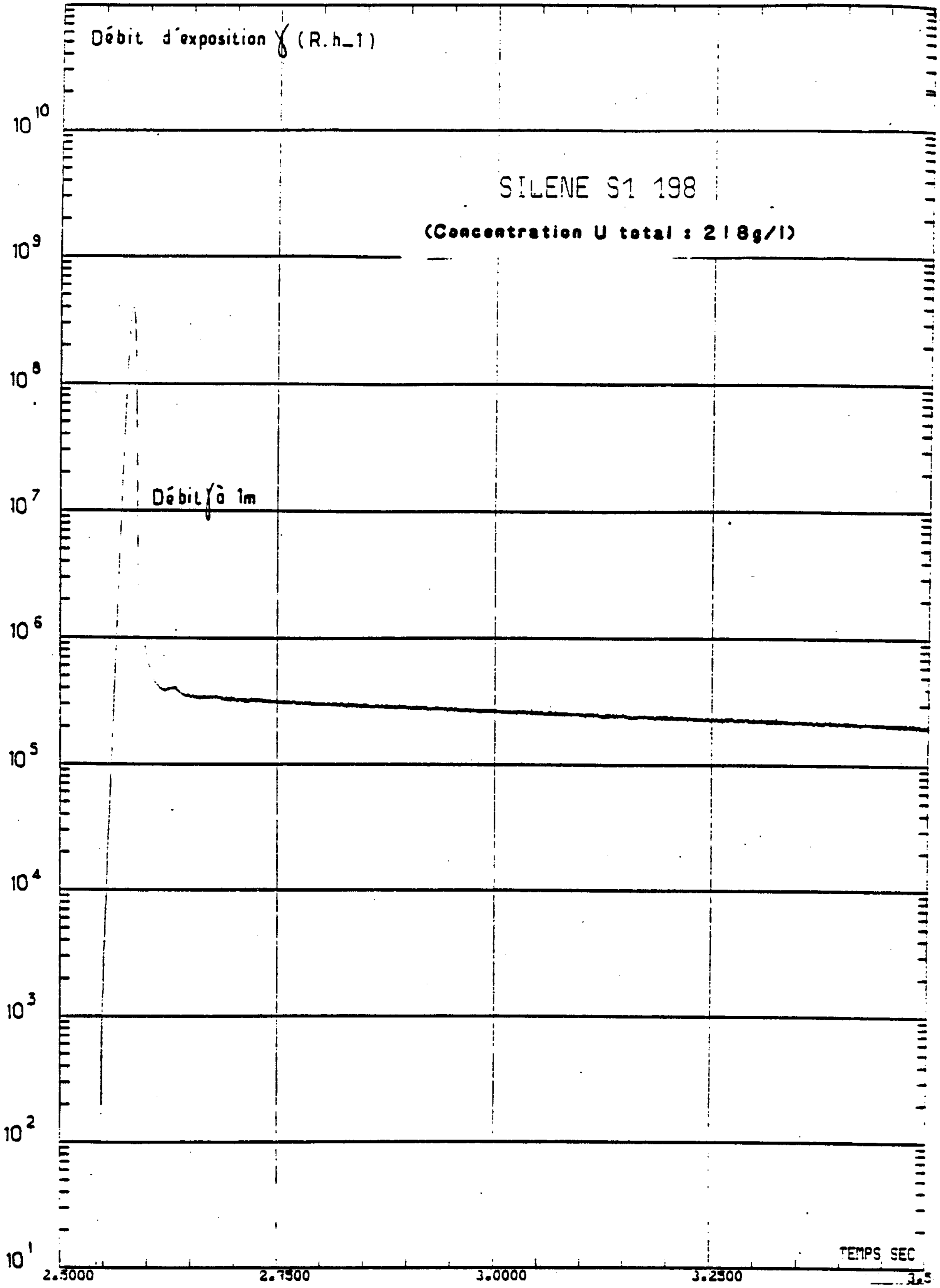


SILENE

Fig. 28 – Expérience du type "Salve"

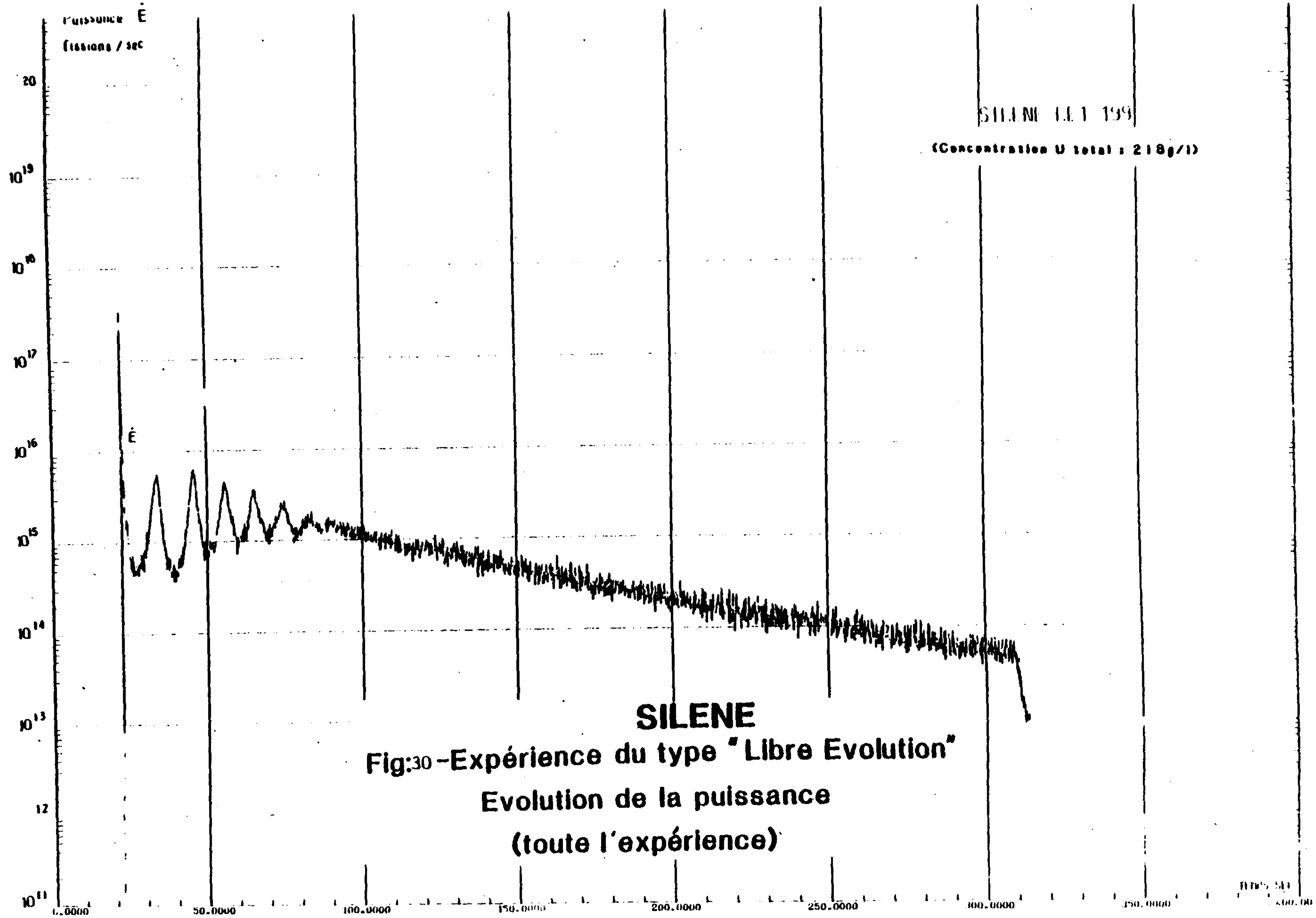
Debit d'exposition γ á 1m de l'axe du réacteur

(toute l'expérience)



SILENE

Fig: 29 – Expérience du type "Salve"
Débit d'exposition γ à 1m de l'axe du réacteur
(premier pic)

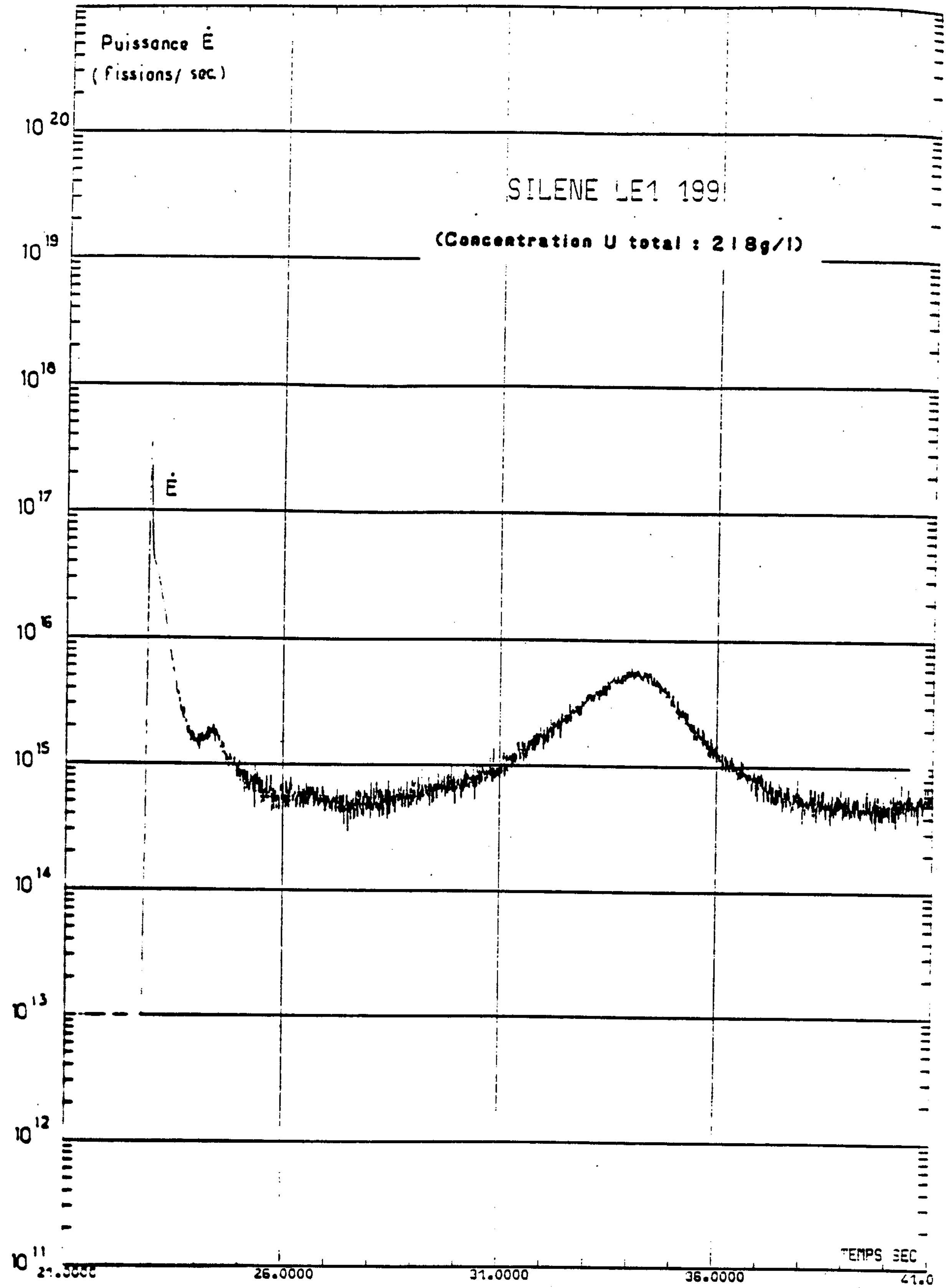


SILENE

Fig:30 - Expérience du type "Libre Evolution"

Evolution de la puissance

(toute l'expérience)



SILENE

Fig:31-Expérience du type "Libre Evolution"

Evolution de la puissance

(premier pic)

SILENE

RESULTATS DES APPROCHES SOUS-CRITIQUES SANS BARRE

Numéro expérience	Concentration g/l U_T	Concentration g/l U_{235}	H_c (cm)	V_c (litres)	M_c (g) U_T	M_c (g) U_{235}
S/c 6-01	220	205	25,02	24,21	5326	4963
S/c 1-02	146,3	136,3	25,79	24,96	3652	3402
S/c 1-03	101,4	94,4	29,61	26,87	2907	2706
S/c 1-04	80,9	75,4	33,72	32,66	2642	2463
S/c 1-06	70,2	65,4	38,87	37,66	2644	2463
S/c 1-05	60,9	56,7	46,23	44,81	2729	2541
S/c 1-07	73,6	68,6	36,64	35,49	2612	2435
S/c 1-08	70,7	65,8	38,19	[illegible]	2616	2435
S/c 1-11	71,3	66,4	38,08	36,89	2630	2450
S/c 1-12	70,7	[illegible]	38,24	37,05	2619	2438
S/c 1-14	70,9	[illegible]	38,02	36,83	2611	2431
S/c 1-15	70,7	65,8	38,45	37,25	2634	2451

SILENE

RESULTS OF THE CALIBRATION ON THE FIRST CORE

NUMBER	$C_{U\,g/l}$	$H_{c\,cm}$	ΔH_{mm}	$H_{f\,cm}$	$V_{f\,l}$	1st PEAK $T_{2\,s}$	$\omega_{s^{-1}}$	$\dot{E}_{fissions\,s^{-1}}$	$E_{fissions}$	$E_{P1\,fissions}$	$E_{P2\,fissions}$	ΔP_{bar}	TEMPERATURE MOYENNE TC1 ET TC2 $\Theta_{i\,°C}$	$\Delta\Theta_{°C\,max}$	DURATION	$N_{f\,fissions}$	NEUTRONS SOURCE
D7-01	220	25.02	3.2	25.34	24.52	3.3	0.187	$1.0\ 10^{18}$	$1.3\ 10^{16}$				21	13.7	300	$4.6\ 10^{16}$	OUI
D3-03	101.4	29.61	4.7	30.08	29.13	3.2	0.217	$1.6\ 10^{16}$	$2.0\ 10^{16}$				22	12.6	240	$5.3\ 10^{16}$	OUI
D3-06	70.3	38.17	7.2	39.39	38.16	4.8	0.139	[illegible]	$3.0\ 10^{16}$				22	10.8	240	$5.7\ 10^{16}$	OUI
D1-12	70.7	38.24	4.7	39.11	37.90	7.3	0.101	$2.4\ 10^{15}$	$2.1\ 10^{16}$				22	13.9	240	$7.4\ 10^{16}$	OUI
D4-23	70.3	38.33	4.3	38.76	37.56	13.6	0.051	$2.0\ 10^{16}$	$1.4\ 10^{16}$				21.5	8.3	540	$4.3\ 10^{16}$	OUI
S1-06	70.2	39.12	14	40.52	39.26	0.42	1.65	$8.6\ 10^{16}$	$1.8\ 10^{16}$	$3.0\ 10^{16}$	$3.7\ 10^{16}$		22	17.7	180	$9.6\ 10^{16}$	NON
S1-08	70.7	38.15	17	39.85	38.61	0.028	24.8	$1.1\ 10^{17}$	$1.0\ 10^{16}$	$3.6\ 10^{16}$	$4.0\ 10^{16}$		22	21.7	180	$1.2\ 10^{17}$	NON
S2-08	70.7	38.14	20	40.14	38.90	0.010	69.3	$7.7\ 10^{17}$	$2.5\ 10^{16}$	$5.5\ 10^{16}$	$5.7\ 10^{16}$		21	25.6	180	$1.4\ 10^{17}$	NON
S3-08	70.7	38.14	25	40.64	39.38	0.0049	142	$3.4\ 10^{18}$	$4.7\ 10^{16}$	$8.2\ 10^{16}$	$8.7\ 10^{16}$	0.5	21	21.3	<60	$8.7\ 10^{16}$	NON
S4-08	70.7	38.14	31	41.24	39.96	0.0040	175	$5.5\ 10^{18}$	$5.8\ 10^{16}$	$9.3\ 10^{16}$	$9.8\ 10^{16}$	1	21	20.6	<60	$9.8\ 10^{16}$	NON
S5-08	70.7	38.14	35	41.64	40.35	0.0023	300	$1.5\ 10^{19}$	$7.5\ 10^{16}$	$1.3\ 10^{17}$	$1.4\ 10^{17}$	2.95	22	41.7	180	$2.5\ 10^{17}$	NON
S1-11	71.3	37.87	31.3	41.00	39.72	0.0031	224	$8.3\ 10^{18}$	$8.3\ 10^{16}$	$1.1\ 10^{17}$	$1.1\ 10^{17}$	1.75	20	37.8	180	$2.1\ 10^{17}$	NON
S1-12	70.7	38.24	40.6	42.30	40.98	0.00178	389	$2.2\ 10^{19}$	$8.4\ 10^{16}$	$1.6\ 10^{17}$	$1.7\ 10^{17}$	4.8	20	29.5	<60	$1.7\ 10^{17}$	NON
S2-12	70.7	38.24	41.6	42.40	41.09	0.00200	347	$1.8\ 10^{19}$	$9.2\ 10^{16}$	$1.5\ 10^{17}$	$1.5\ 10^{17}$	4	21	47.2	120	$2.7\ 10^{17}$	NON
S1-16	70.7	38.26	41.7	42.43	41.11	0.00185	376	$2.1\ 10^{19}$	$9.3\ 10^{16}$	$1.6\ 10^{17}$	$1.6\ 10^{17}$	4.3	18.6	26.8	<60	$1.6\ 10^{17}$	NON
S2-16	70.7	38.26	43.6	42.62	41.30	0.00168	413	$2.4\ 10^{19}$	$9.2\ 10^{16}$	$1.7\ 10^{17}$	$1.7\ 10^{17}$	4.95	18.6	29	<60	$1.7\ 10^{17}$	NON
S1-22	71.2	37.63	30	40.63	39.37	0.0031	224	$7.8\ 10^{18}$	$6.7\ 10^{16}$	$1.0\ 10^{17}$	$1.1\ 10^{17}$	1.55	20	26.4	<60	$1.1\ 10^{17}$	NON
S2-22	71.2	37.63	38	41.43	40.15	0.0023	301	$1.4\ 10^{19}$	$8.8\ 10^{16}$	$1.2\ 10^{17}$	$1.3\ 10^{17}$	2.95	20.5	24.9	<60	$1.3\ 10^{17}$	NON
S3-22	71.2	37.63	42.1	41.84	40.54	0.00172	403	$2.2\ 10^{19}$	$9.0\ 10^{16}$	$1.6\ 10^{17}$	$1.6\ 10^{17}$	4.95			<60	$1.6\ 10^{17}$	NON
S4-22	71.2	37.63	28	40.43	39.18	0.0039	178	$4.9\ 10^{18}$	$5.5\ 10^{16}$	$8.7\ 10^{16}$	$9.2\ 10^{16}$	0.9	20.5	17.6	<60	$9.2\ 10^{16}$	NON
S5-22	71.2	37.63	15.5	39.18	37.96	0.090	7.7	$2.2\ 10^{16}$	$1.1\ 10^{16}$	$3.4\ 10^{16}$	$3.8\ 10^{16}$		20.5	9.3	<60	$3.8\ 10^{16}$	NON
S6-22	71.2	37.63	44	42.03	40.73	0.00177	392	$2.1\ 10^{19}$	$9.7\ 10^{16}$	$1.5\ 10^{17}$	$1.6\ 10^{17}$	4.65			<60	$1.5\ 10^{17}$	NON
S1-23	70.3	38.51	44	42.91	41.58	0.0037	187	$6.7\ 10^{18}$	$6.4\ 10^{16}$	$9.9\ 10^{16}$	$1.0\ 10^{17}$	1.3	21	19	<60	$1.0\ 10^{17}$	NON
S2-23	70.3	38.51	44	42.91	41.58	0.0037	187	$6.8\ 10^{18}$	$6.4\ 10^{16}$	$1.0\ 10^{17}$	$1.0\ 10^{17}$	1.3	21	19.1	<60	$1.1\ 10^{17}$	NON
LE1-12	70.7	38.24	60.1	44.25	42.88	0.019	36.5	$3.1\ 10^{18}$	$1.6\ 10^{16}$	$5.0\ 10^{16}$	$5.4\ 10^{16}$		21	64.3	360	$4.0\ 10^{17}$	OUI

S6-22 fiss/[illegible] first pulse = 2.4E[illegible] f/l
Total first pulse 3.9E15 f/l

1 - A table of results from all supercritical tests.

2 - Critical characteristics of the core (result table and graph).

3 - The variation of the effect produced on reactivity by one millimeter of solution above the critical height (result table and graph).

4 - The variation of the feedback term as a function of concentration (graph).

5 - The neutron constants determined by calculation and used in evaluating reactivity.

APPENDIX 2

RESULTS OF THE SILENE REACTOR CALIBRATION CAMPAIGN

In order to select the optimal characteristics for routine operation of the Silene reactor and meet safety requirements, a reactor calibration campaign was conducted in 1974. This campaign made it possible to determine, through computation or measurement, the principal parameters and neutron constants necessary for operation and for interpretation of kinetic experiments.

The results of these tests are presented separately because they were obtained from the first reactor core tank whose characteristics differ slightly from those of the tanks used previously. The only differences were the thickness of the stainless steel for the cover (20 mm) and for the tank bottom (16 mm). The critical conditions thus varied only slightly from current measurements. Nonetheless, since these tests covered a wide concentration range, from 60 to 220 g/l, and included kinetic parameter measurements (effect of one millimeter and feedback effects), it appeared useful to add this information to the present summary of Silene experiments.

Detailed results are found in technical note DSN/SEESNC No. 124.

This summarized presentation consists of:

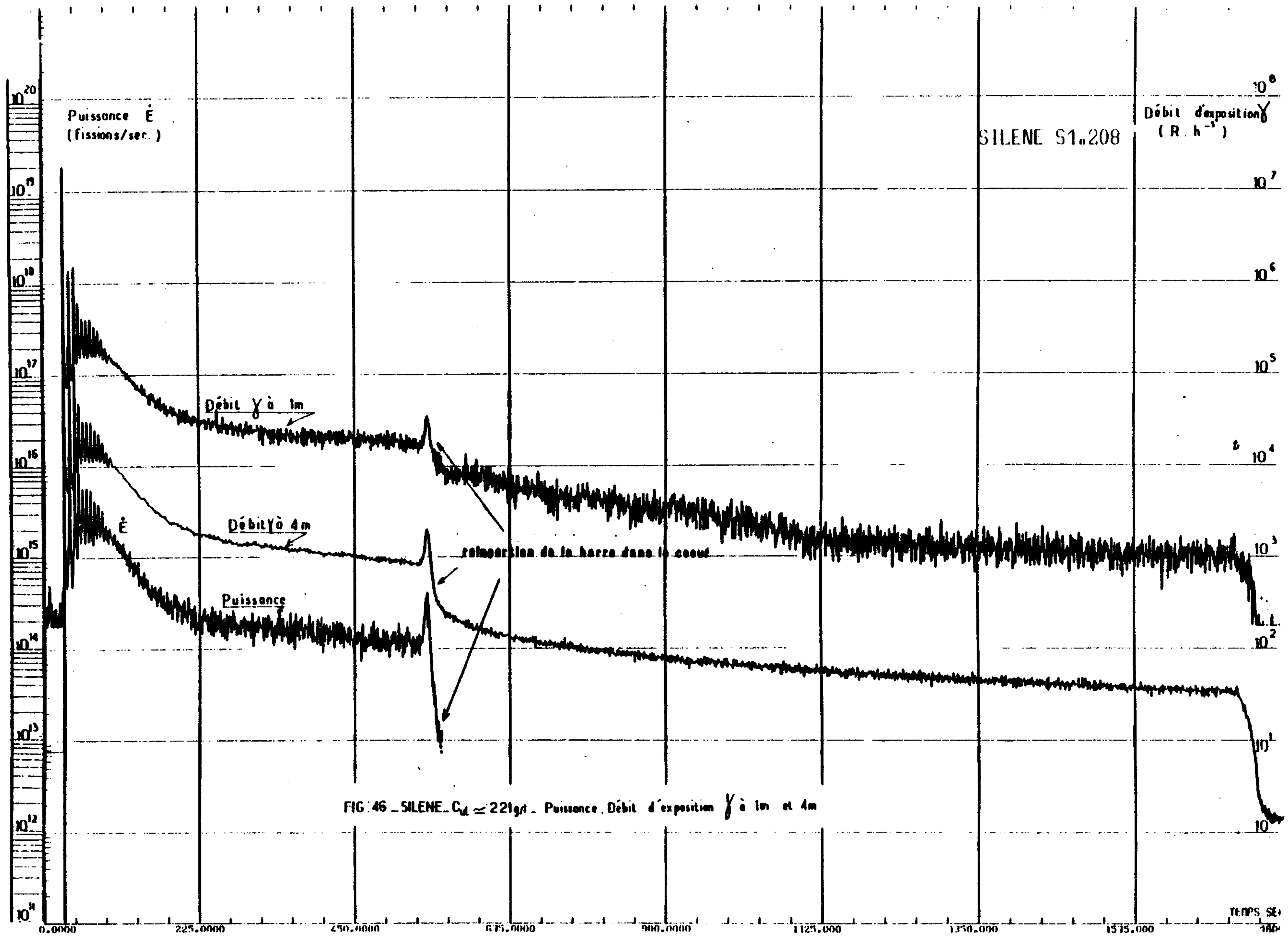


FIG. 46 _ SILENE _ $C_U \simeq 221$ g/l _ Puissance, Débit d'exposition γ à 1m et 4m

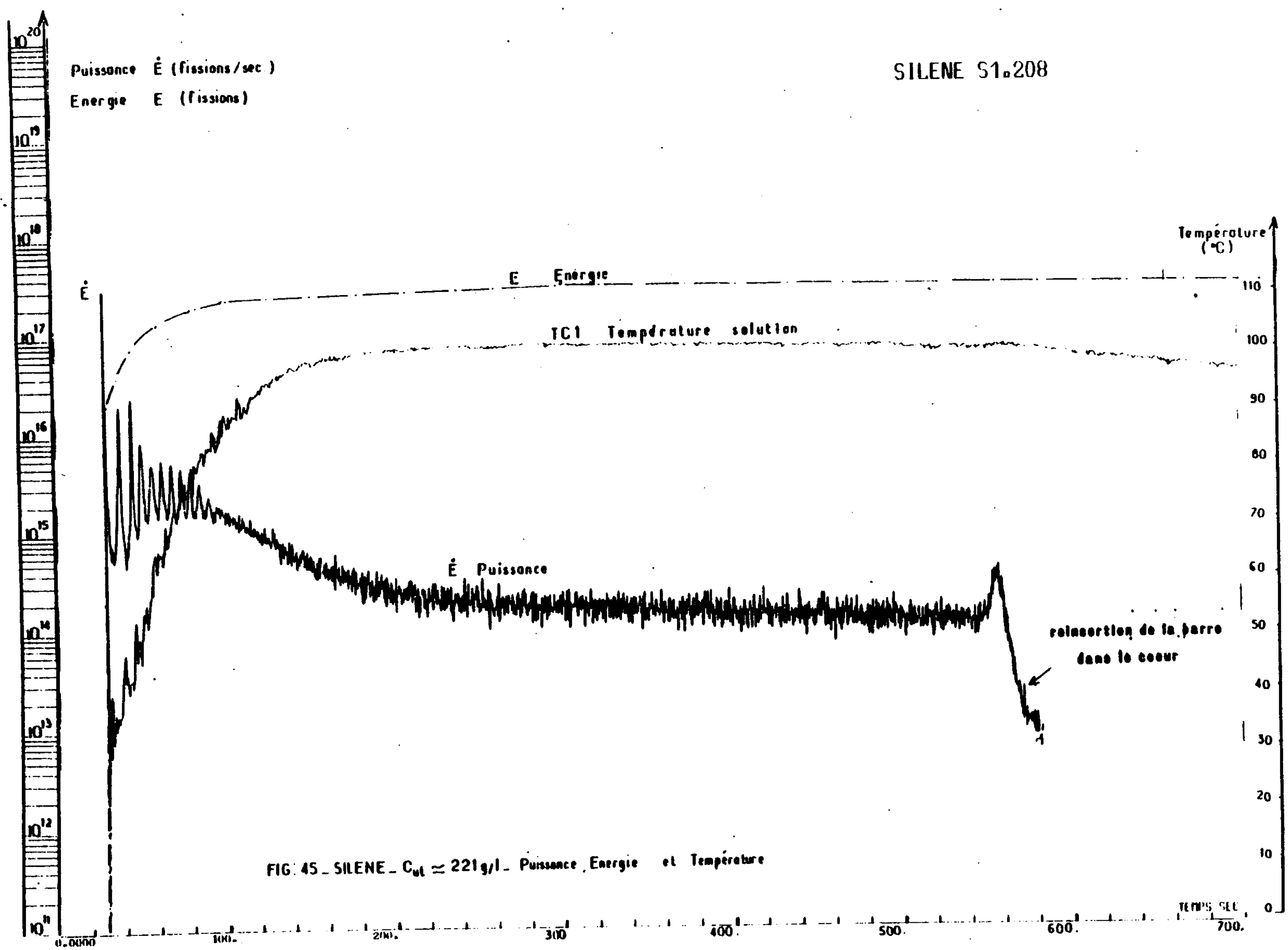


FIG. 45 _ SILENE _ $C_{ut} \simeq 221$ g/l _ Puissance, Energie et Température

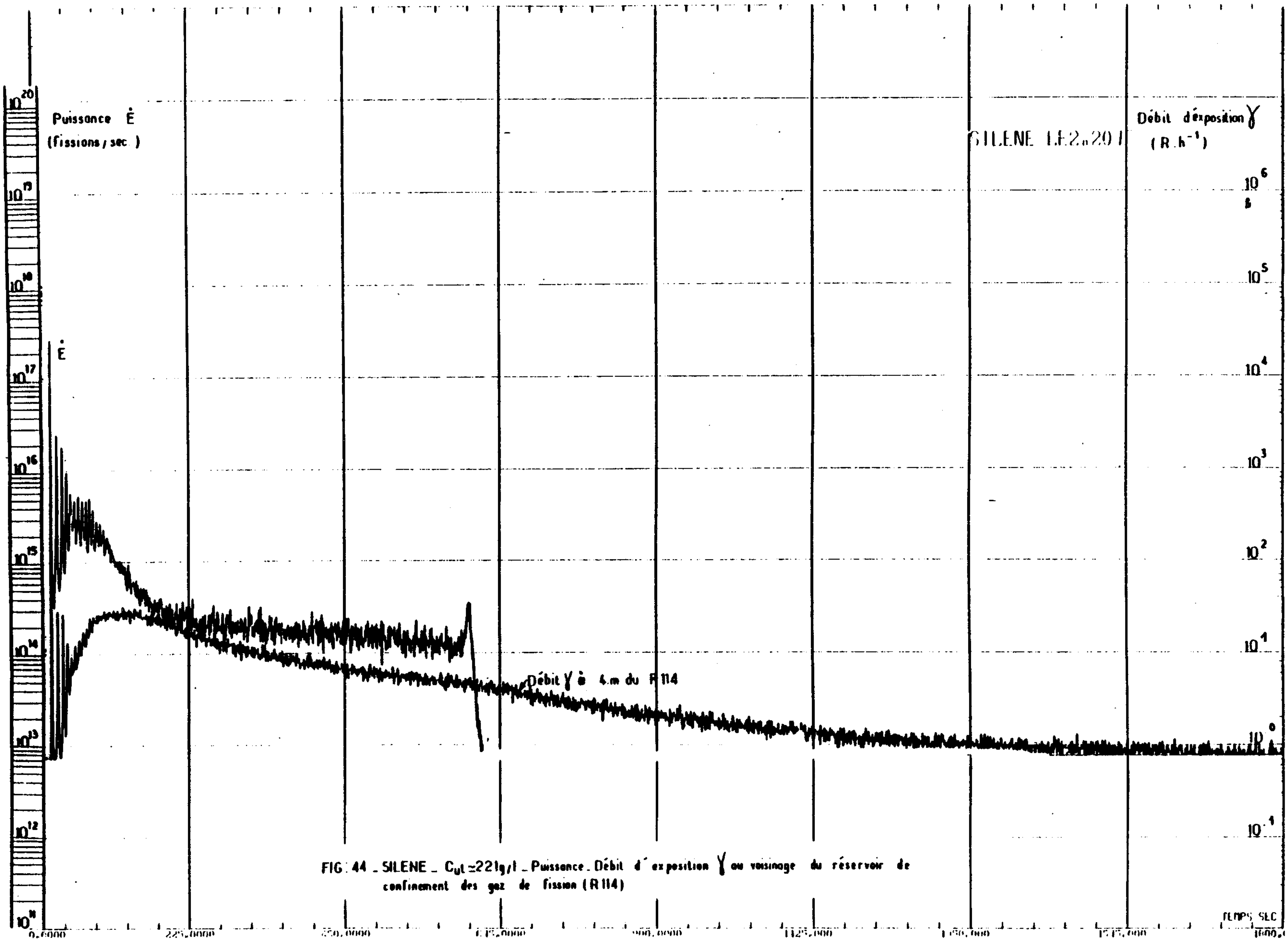


FIG. 44 _ SILENE _ $C_{Ut} \simeq 221 g/l$ _ Puissance _ Débit d'exposition γ au voisinage du réservoir de confinement des gaz de fission (R114)

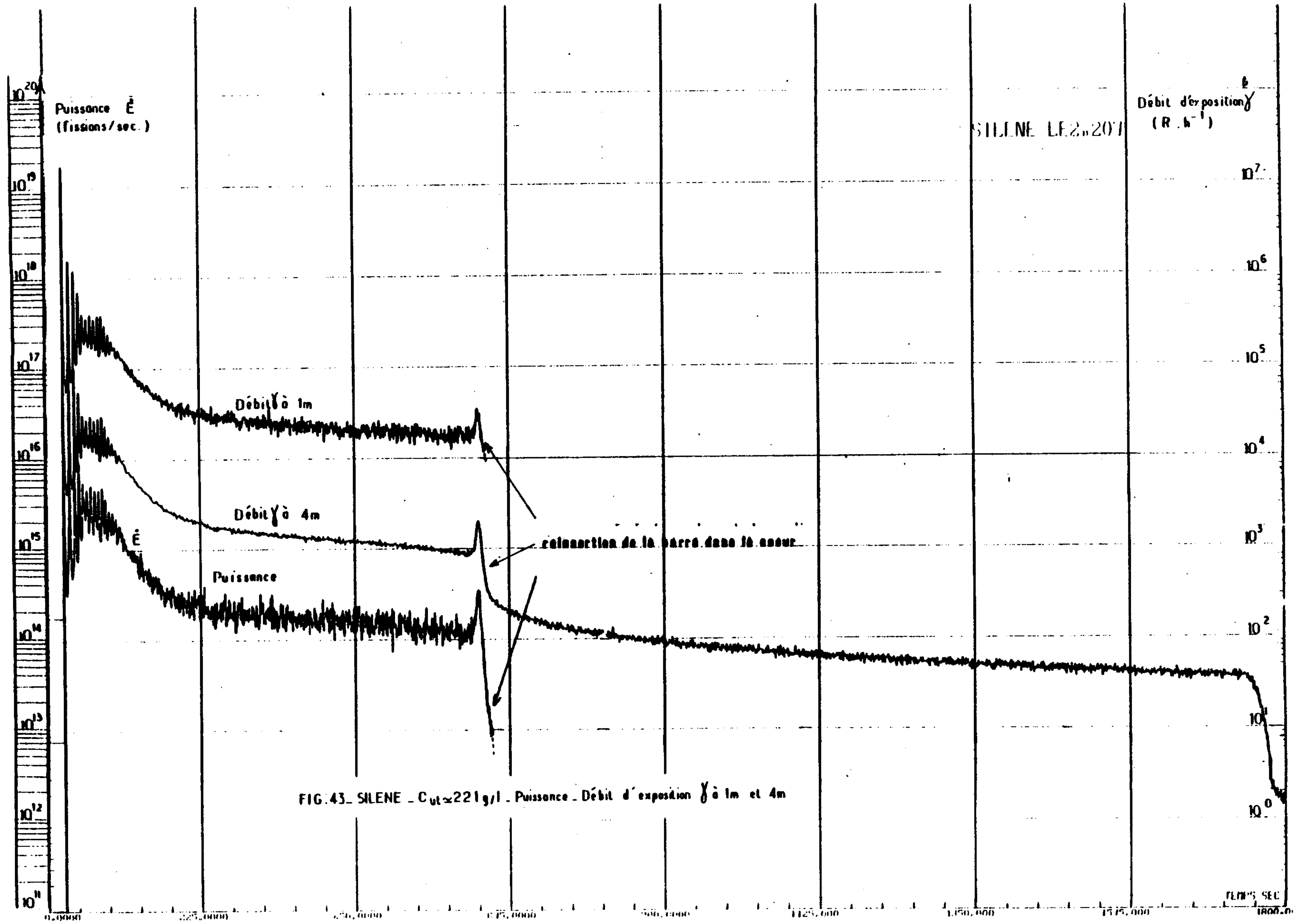


FIG.43_ SILENE _ $C_{ut} \simeq 221$ g/l _ Puissance _ Débit d'exposition γ à 1m et 4m

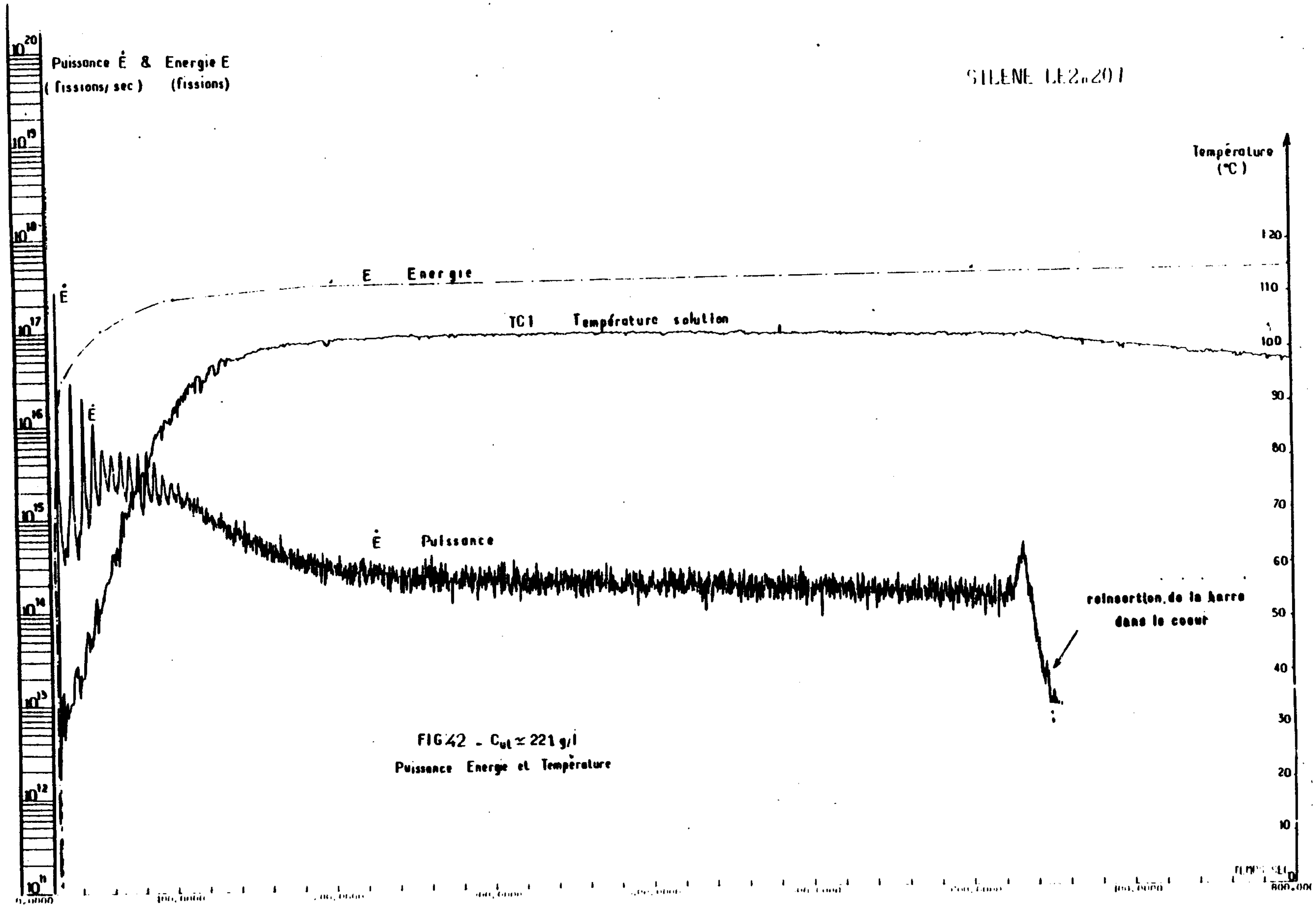


FIG 42 - $C_{ut} \simeq 221$ g/l
Puissance Energie et Température

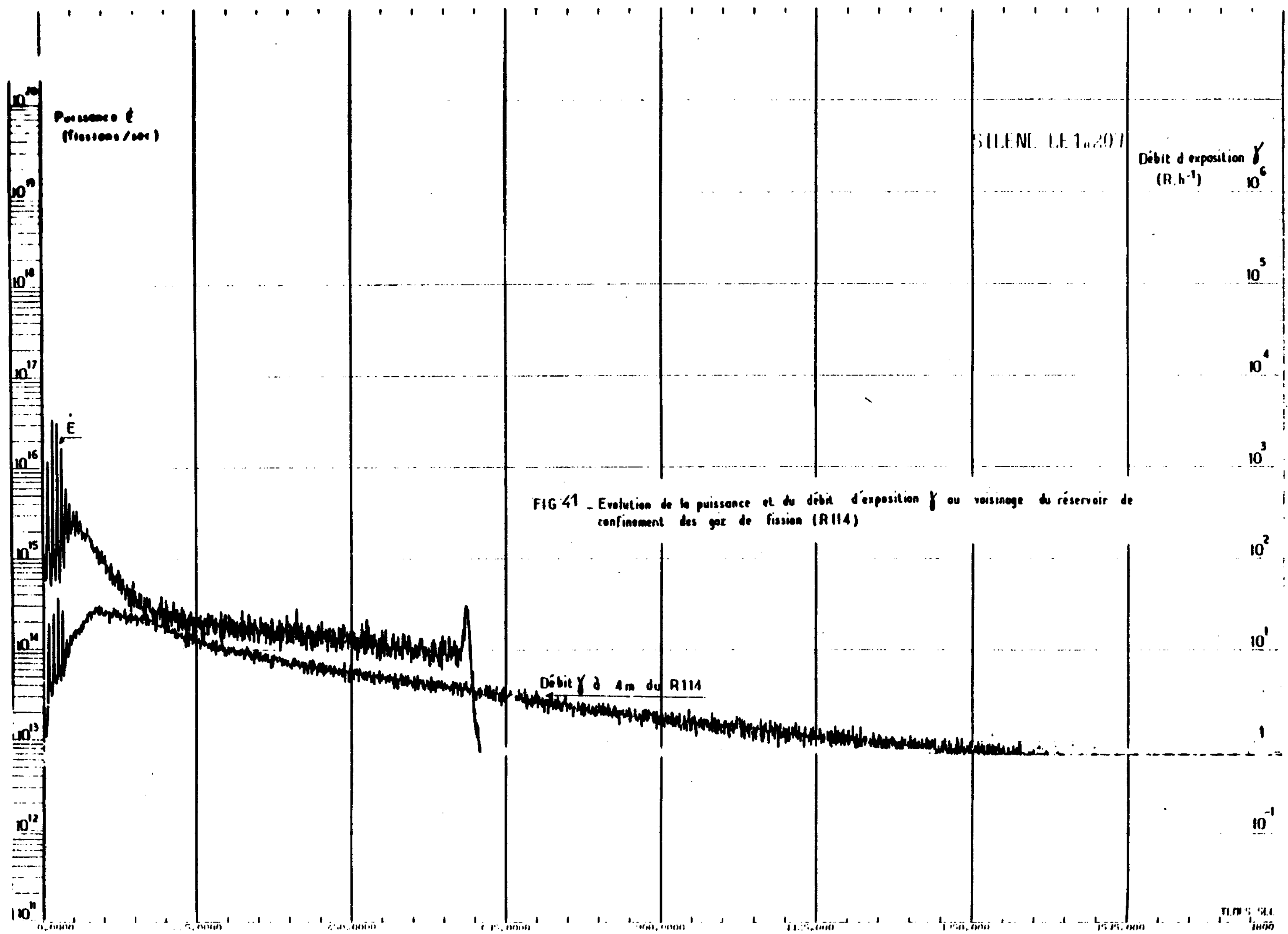


FIG 41 _ Evolution de la puissance et du débit d'exposition γ au voisinage du réservoir de confinement des gaz de fission (R114)

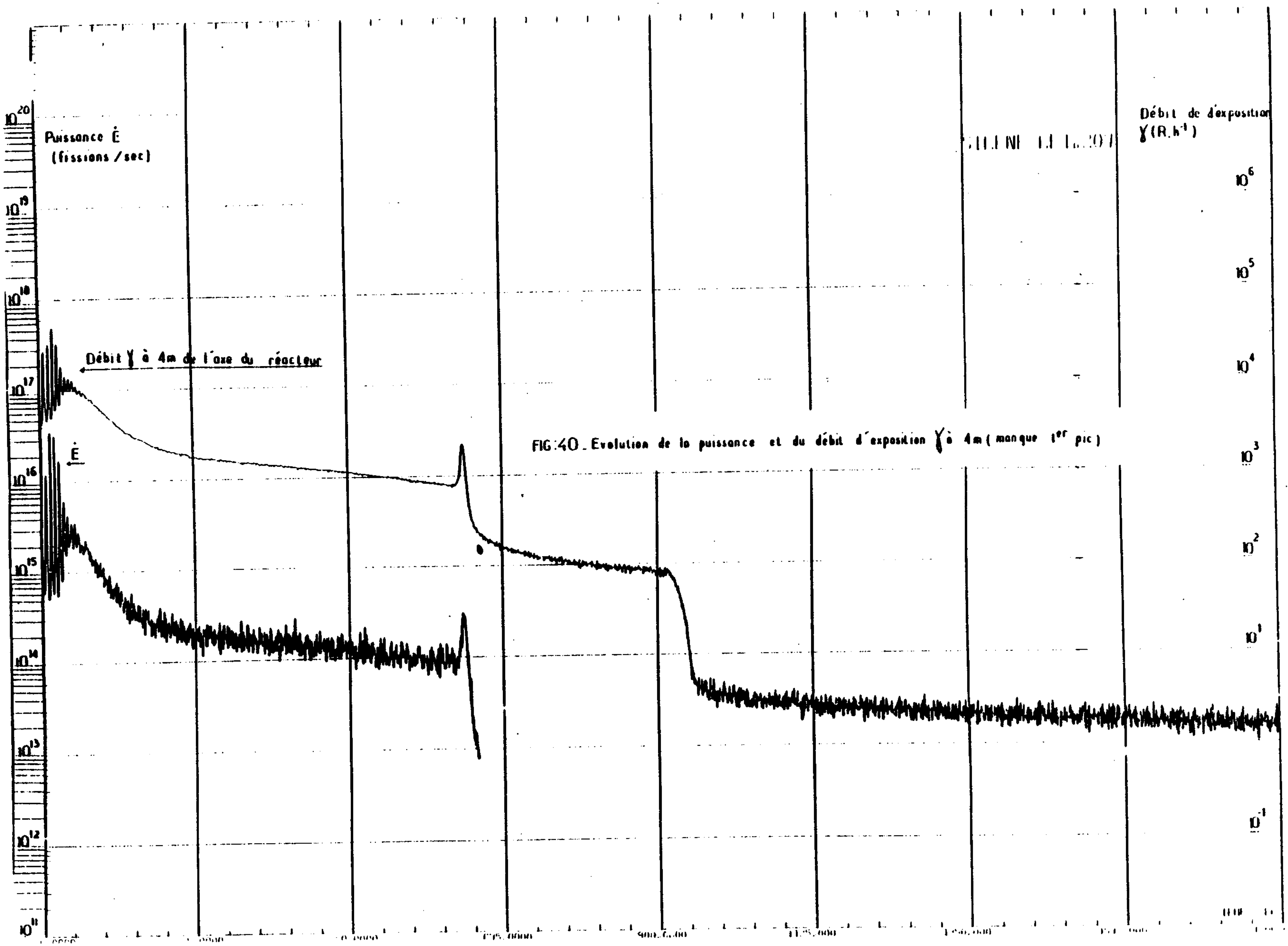
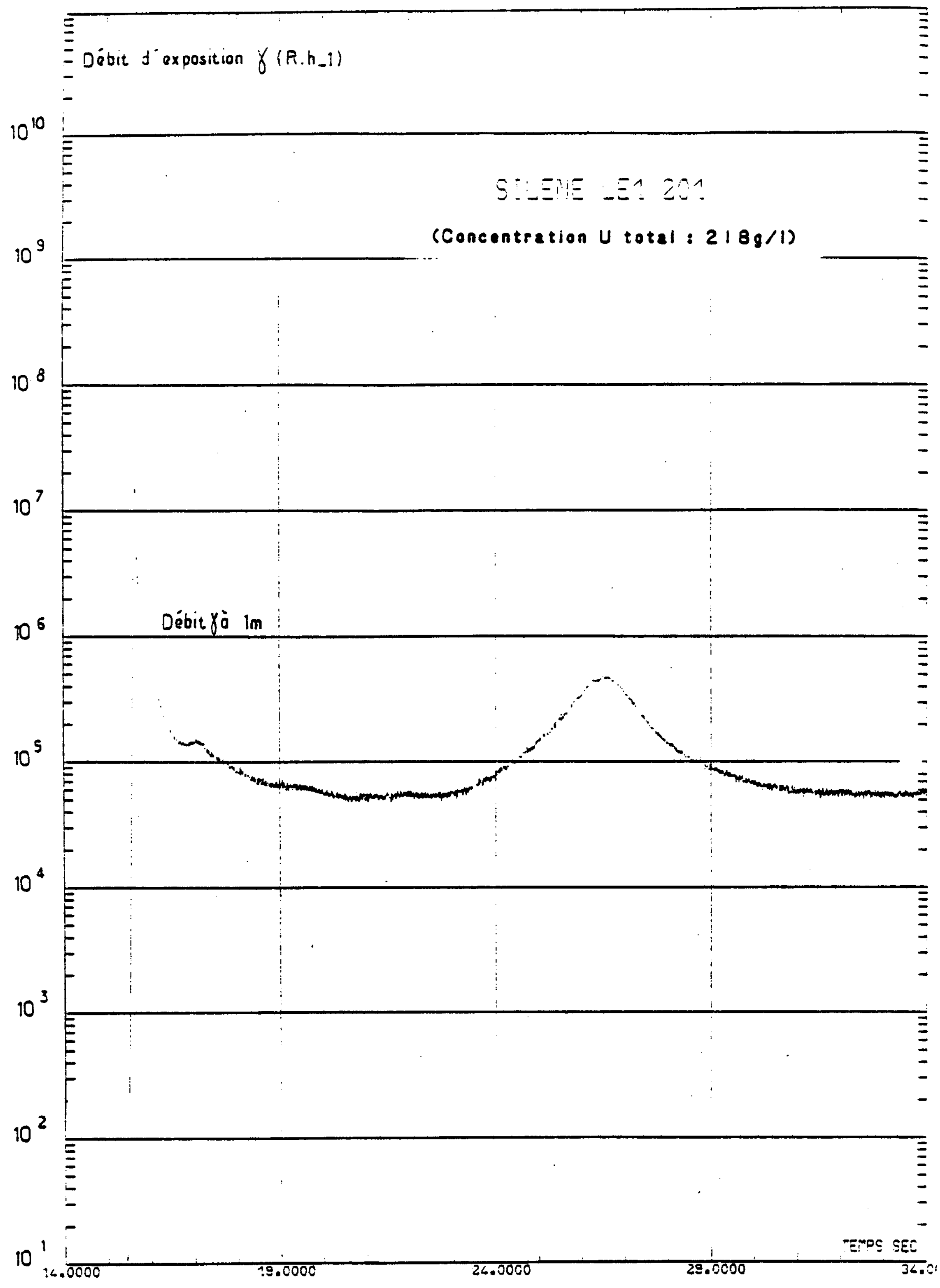
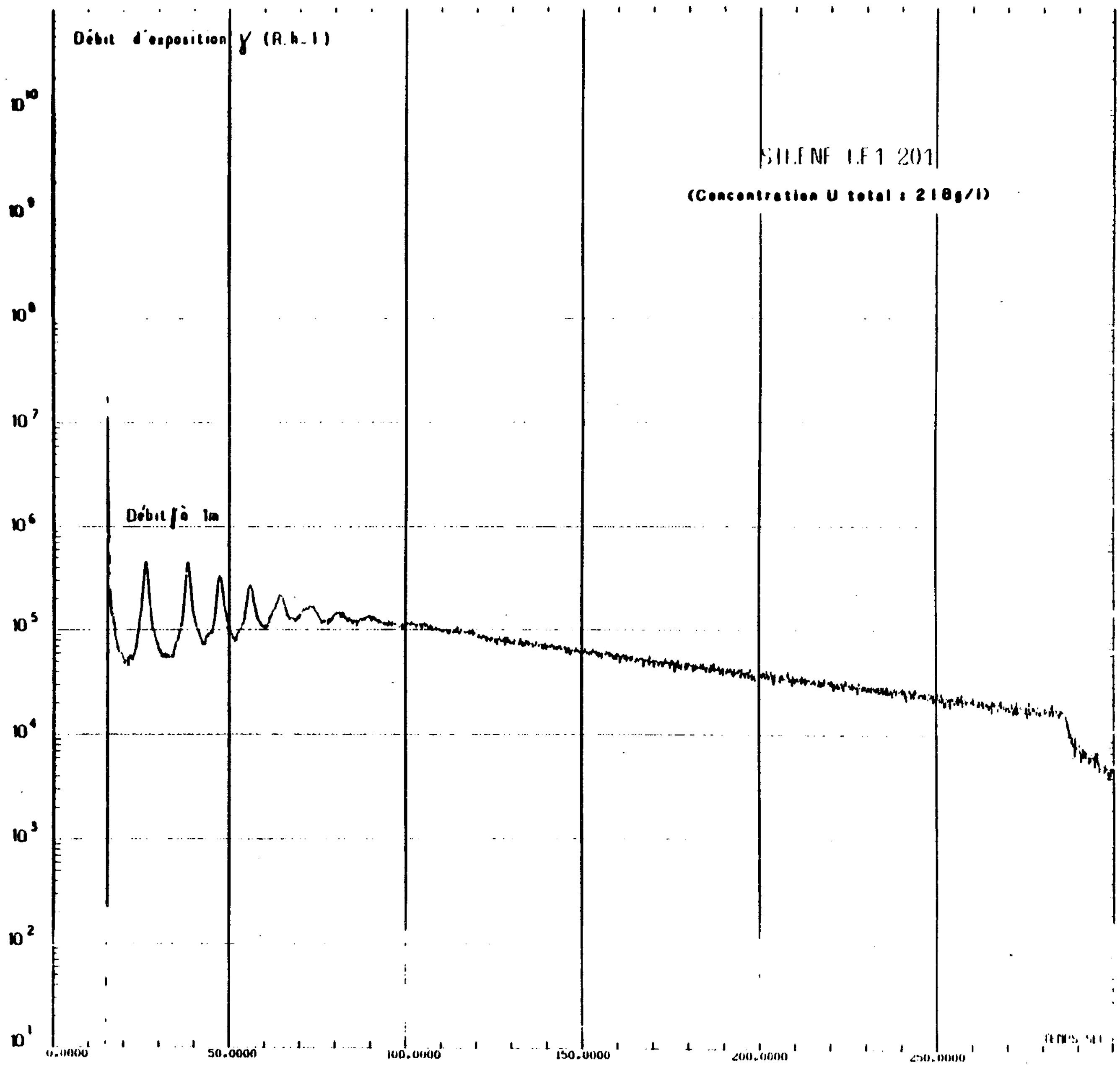


FIG:40 . Evolution de la puissance et du débit d'exposition γ à 4m (manque 1er pic)



SILENE

Fig:39 Expérience du type "Libre Evolution"
Debit d'exposition γ á 1m de l'axe du réacteur
(premier pic)

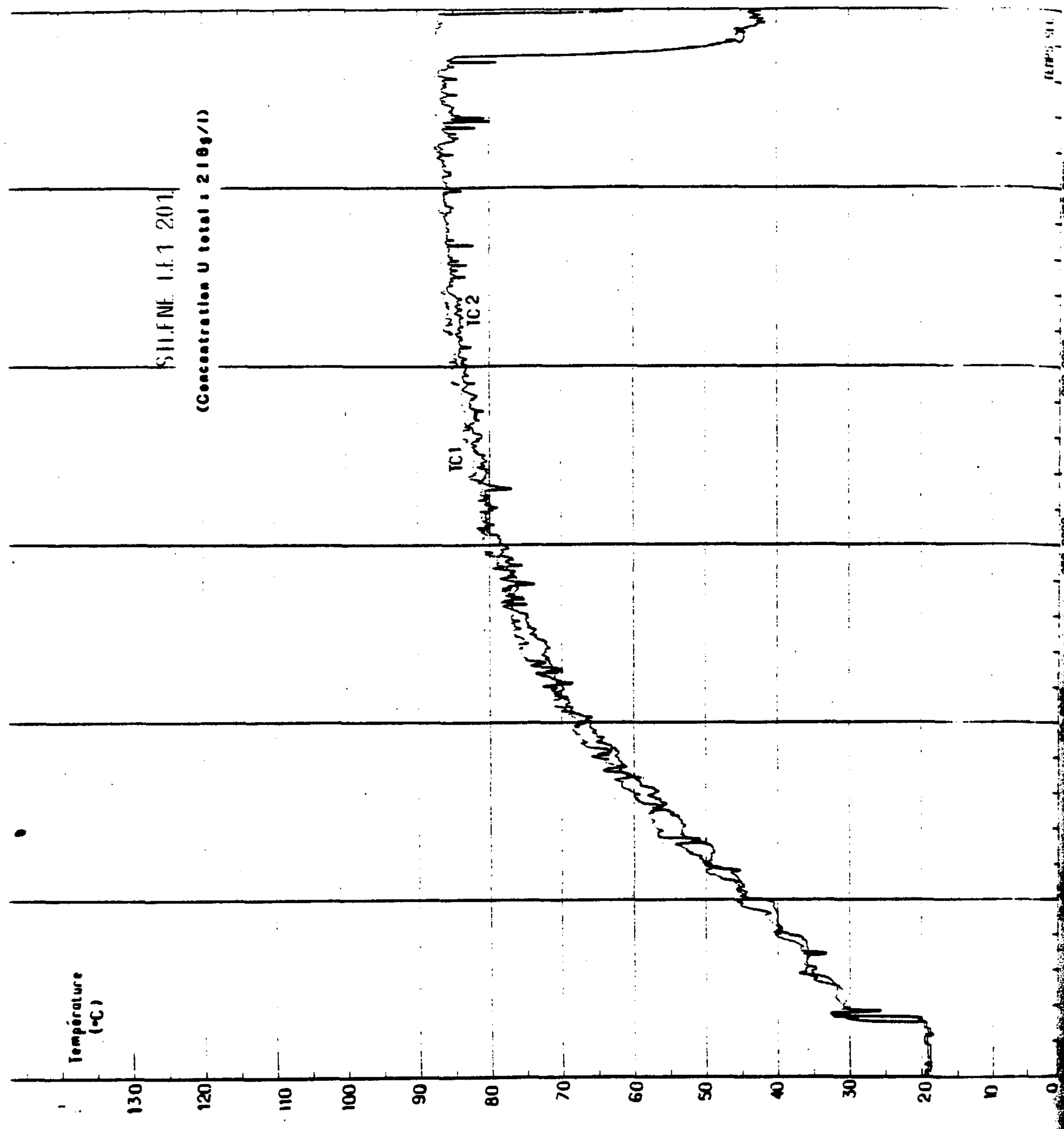


SILENE

Fig3b -Expérience du type "Libre Evolution"

Debit d'exposition γ á 1m de l'axe du réacteur

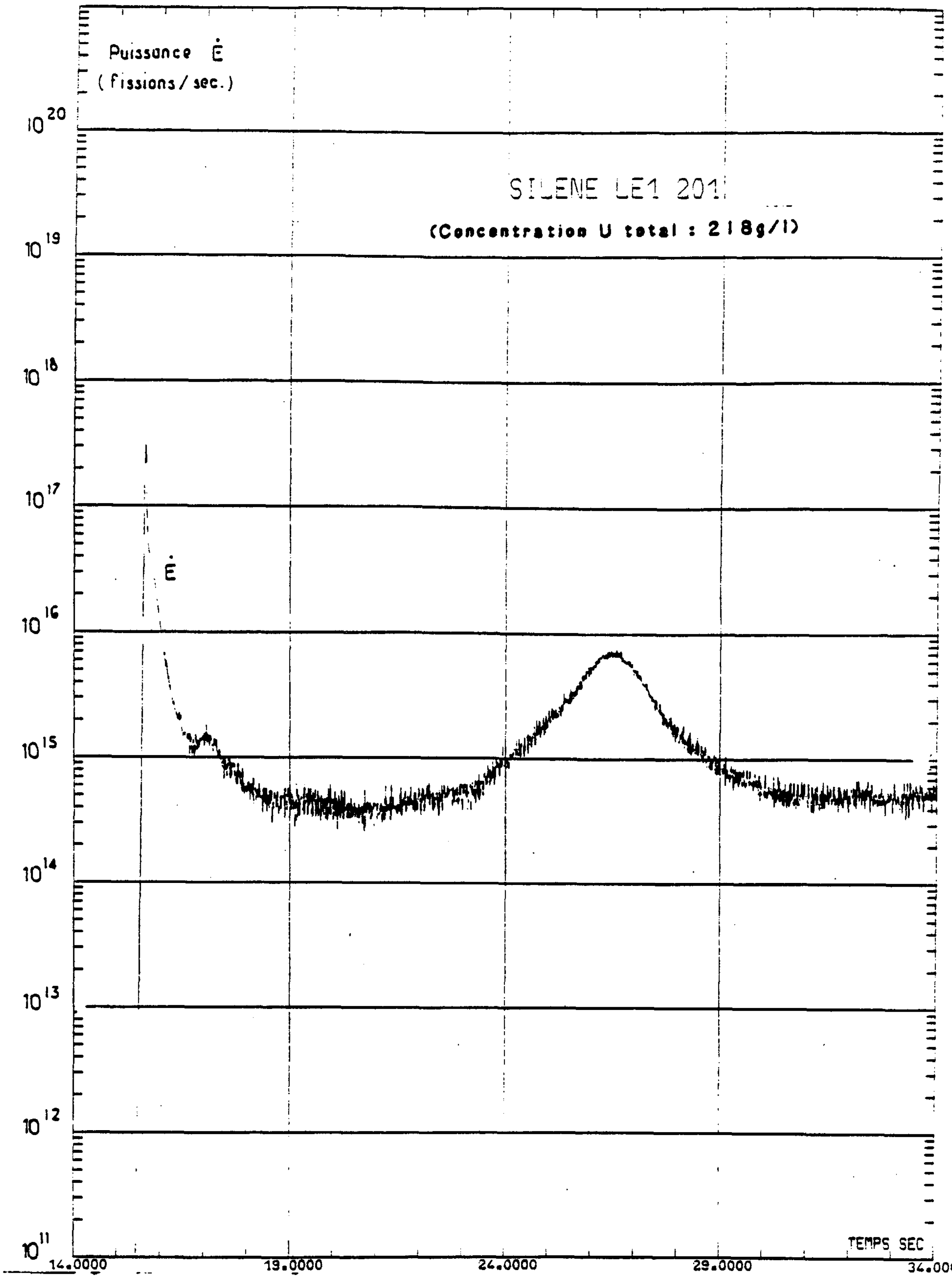
(toute l'expérience)



SILENE

Fig.37–Expérience du type "Libre Evolution"

Evolution de la température au sein du réacteur

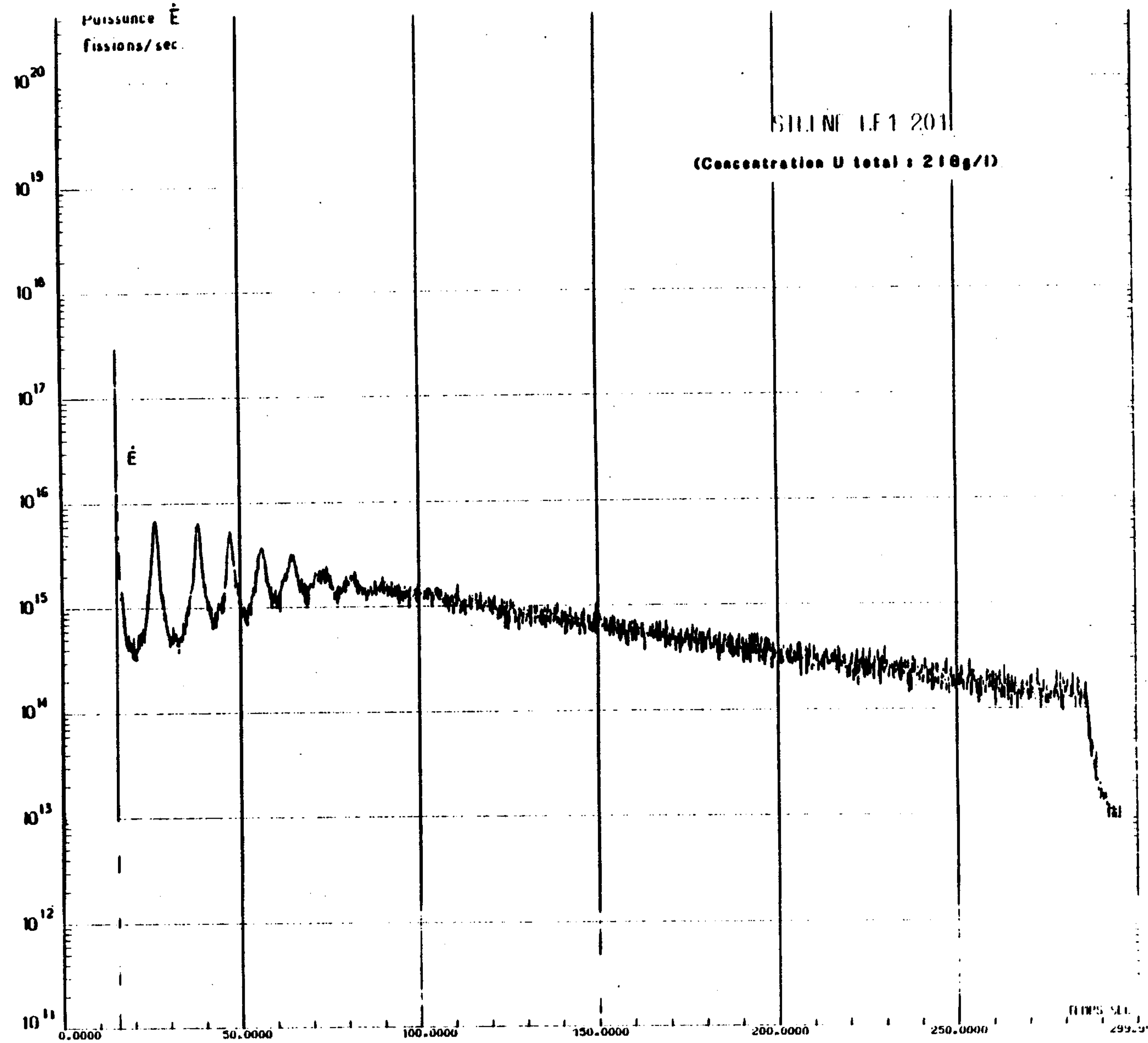


SILENE

Fig:36-Expérience du type "Libre Evolution"

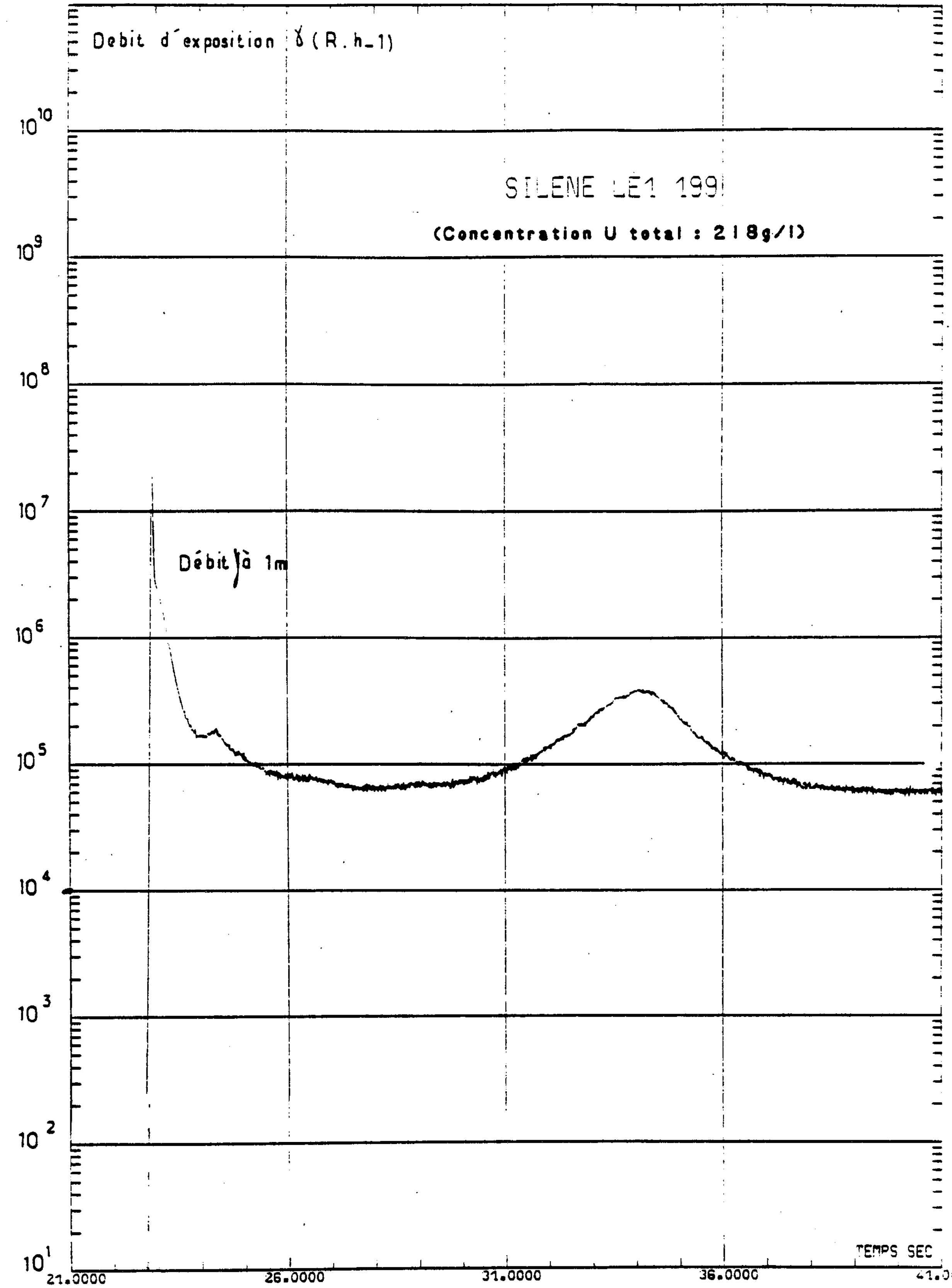
Evolution de la puissance

(premier pic)



SILENE

Fig.35 – Expérience du type "Libre Evolution"
Evolution de la puissance
(toute l'expérience)

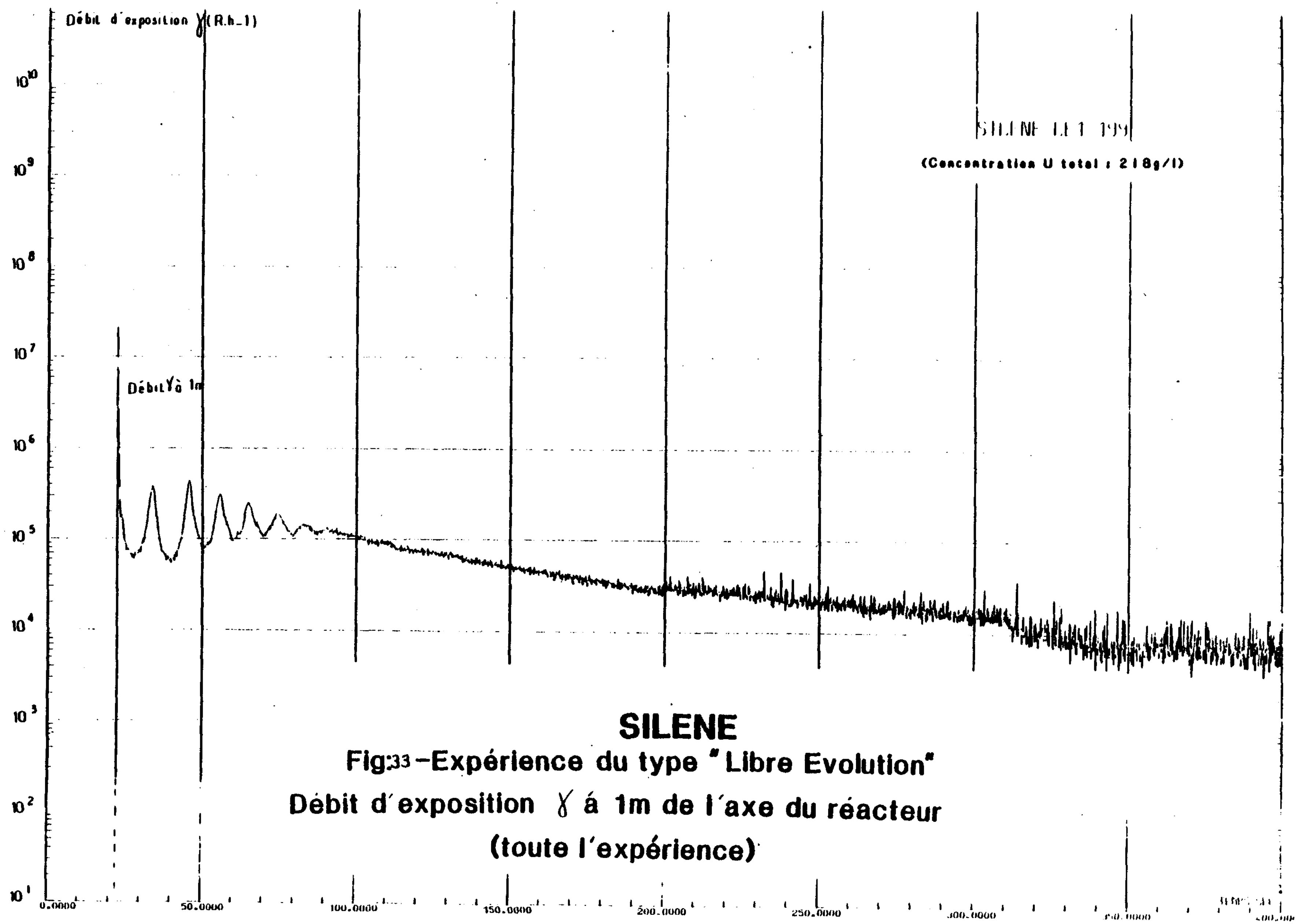


SILENE

Fig:34-Expérience du type "Libre Evolution"

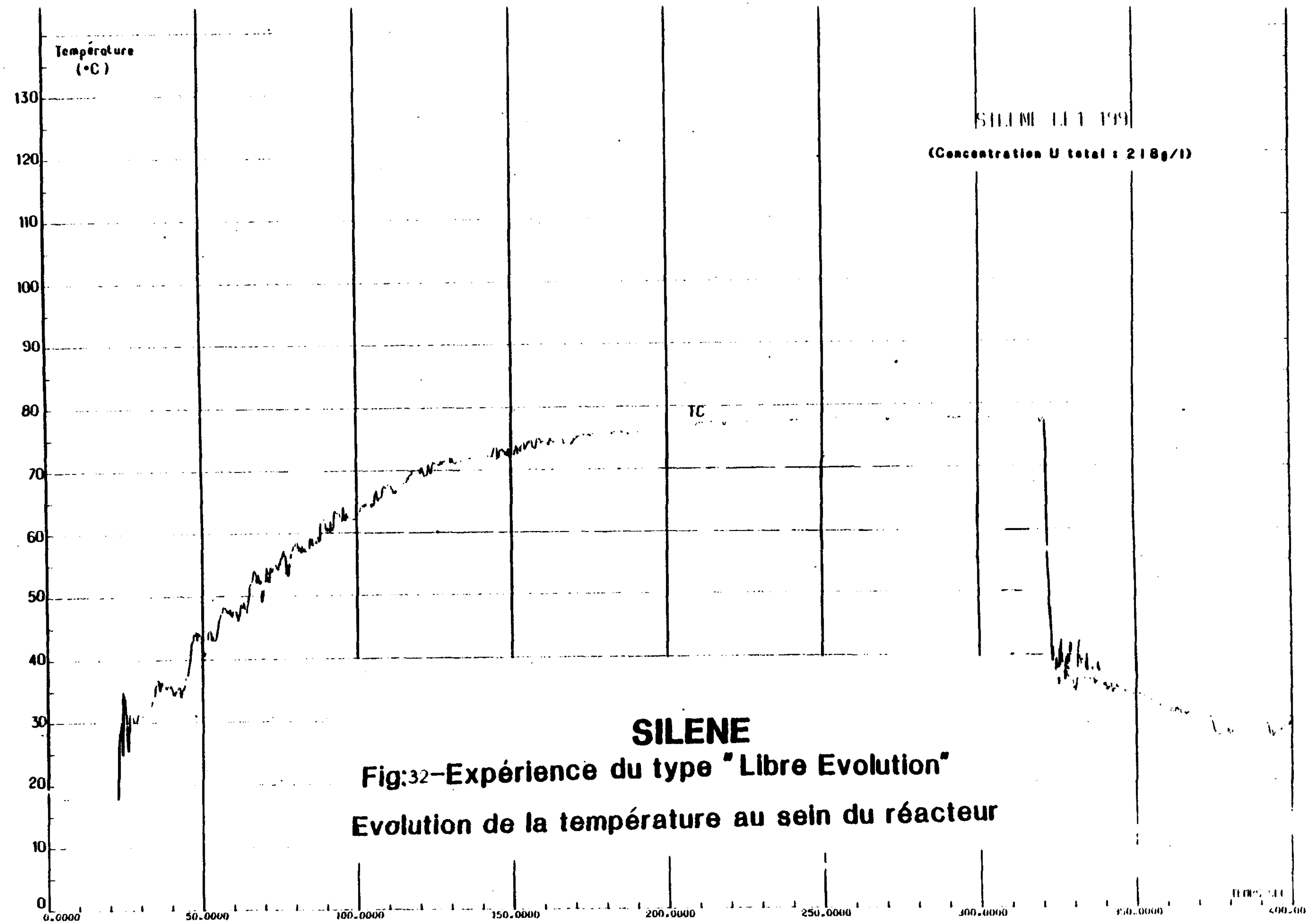
Débit d'exposition γ á 1m de l'axe du réacteur

(premier pic)



SILENE

Fig:33 – Expérience du type "Libre Evolution"
Débit d'exposition γ á 1m de l'axe du réacteur
(toute l'expérience)



SILENE

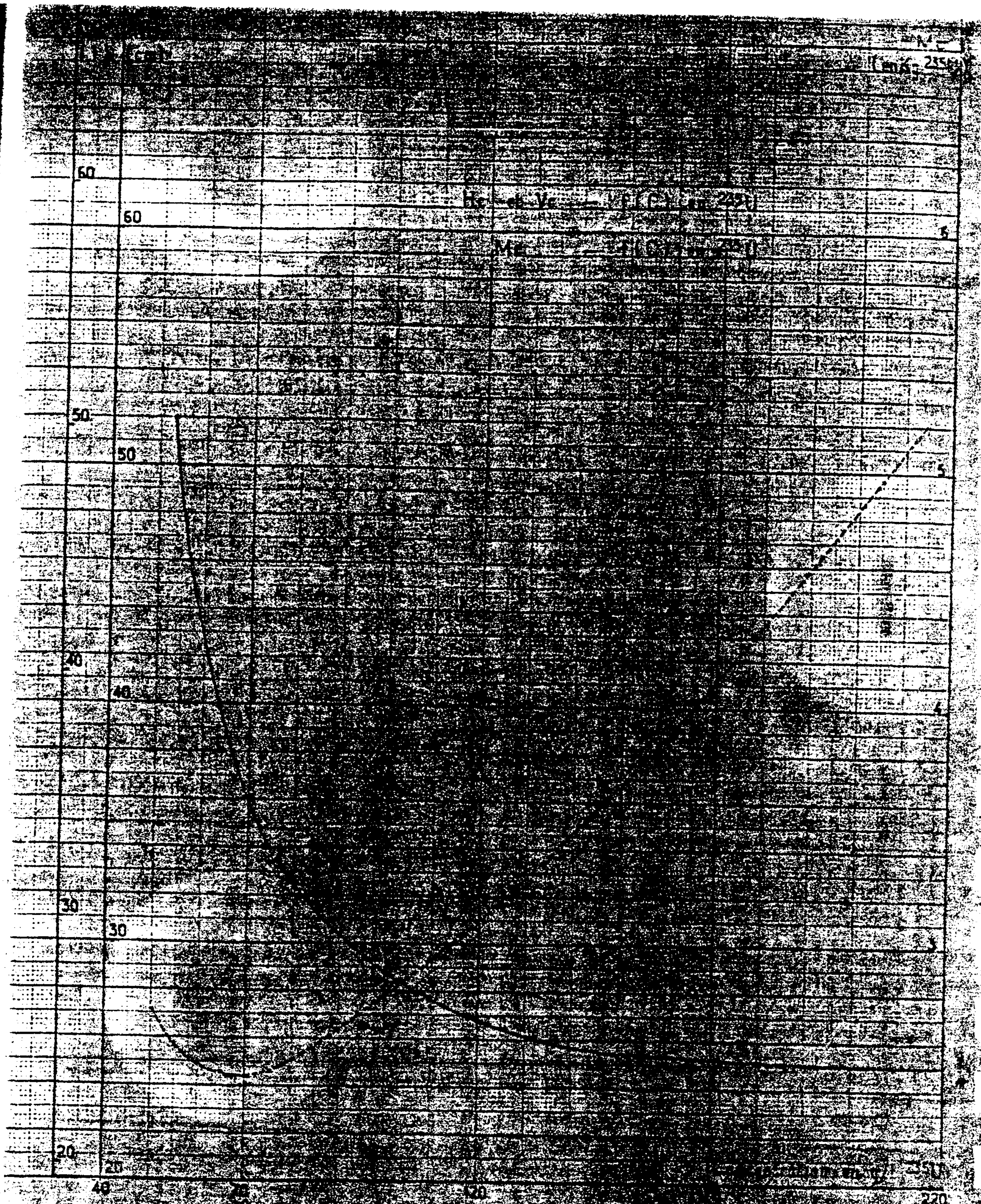
Fig:32–Expérience du type "Libre Evolution"

Evolution de la température au sein du réacteur

CONSTANTES [illegible] DU REACTEUR [illegible]

(CONFIGURATION SANS ECRAN)

C (U_T) (g/l)	60,9	70,2	80,9	[illegible]	146,3	220
d	1,1471	1,1673	1,1743	[illegible]	1,2556	1,3860
H^+ [N]	1,91	2,25	1,91	[illegible]	1,79	2,84
NO_3^- [N]	[illegible]	[illegible]	2,61	[illegible]	2,98	4,71
H_c (cm)	46,23	[illegible]	33,72	[illegible]	25,79	25,00
$\bar{v}$ (cm/s)	1,608.10^7	1,624.10^7	1,641.10^7	[illegible]	1,727.10^7	1,802.10^7
v_{th} (cm/s)	[illegible]	2,932.10^5	2,977.10^5	[illegible]	[illegible]	3,561.10^5
ℓ (μs)	37,58	33,06	30,00	[illegible]	[illegible]	13,00
Σ_a (cm^{-1})	[illegible]	[illegible]	[illegible]	[illegible]	0,1691	0,2236
$\Sigma_{a\,th}$ (cm^{-1})	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1768
L^2 (cm^2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,9065
τ (cm^2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29,15
D_{th} (cm)	[illegible]	[illegible]	[illegible]	[illegible]	0,1887	0,2027
ε_1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,38
ε_2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,33
ε_3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,35
ε_4	[illegible]	[illegible]	1,22	[illegible]	[illegible]	1,34
ε_5	[illegible]	[illegible]	1,25	[illegible]	[illegible]	1,35
ε_6	1,20	[illegible]	1,20	[illegible]	[illegible]	1,20
β_{eff} en pcm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	853
Groupe	1	2	3	4	5	6
β_i %	[illegible]	[illegible]	0,126	[illegible]	[illegible]	0,026
λ_i (s^{-1})	0,0124	0,0305	0,111	[illegible]	[illegible]	3,00



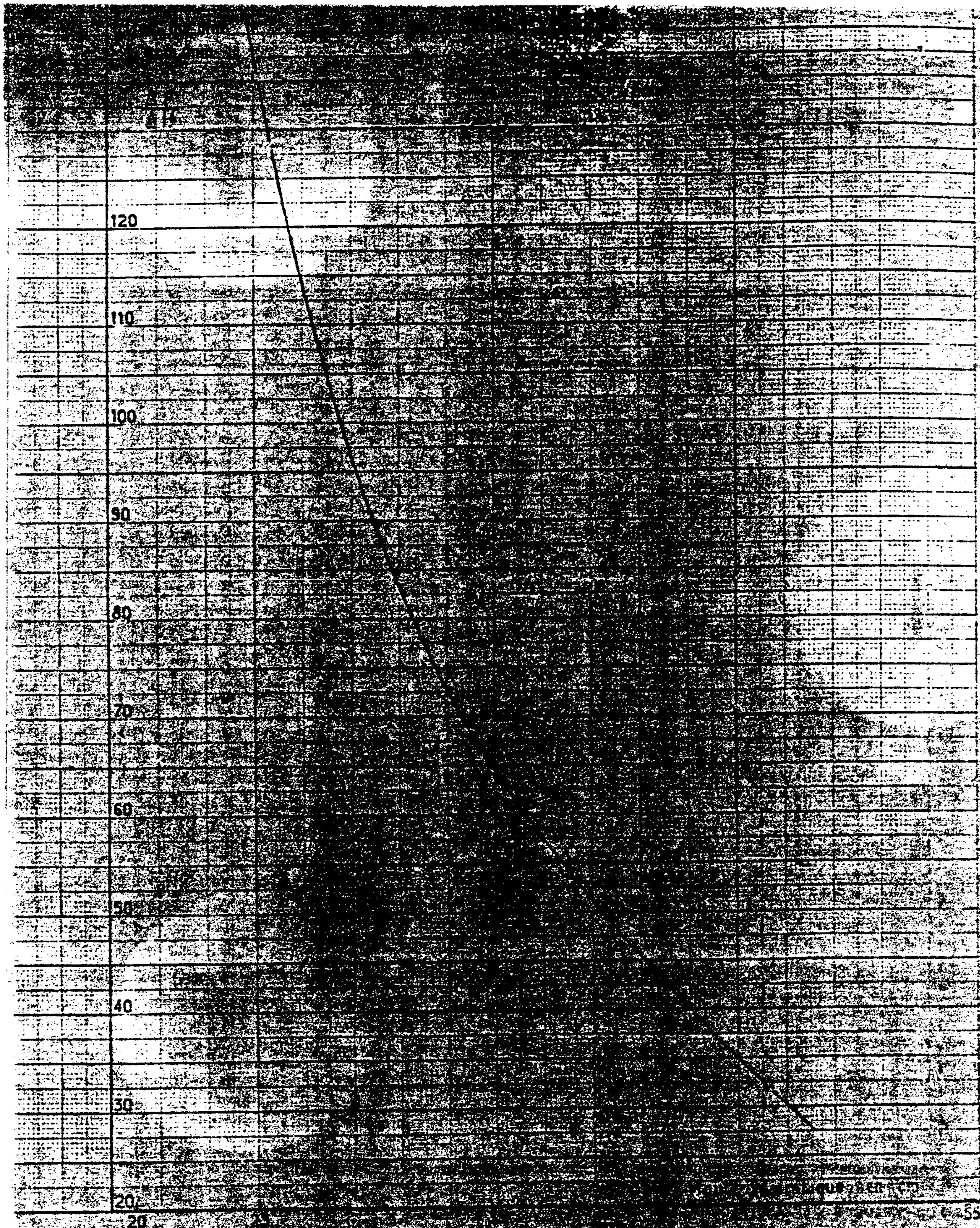
- STILENE - Caractéristiques critiques du [illegible]

[illegible]

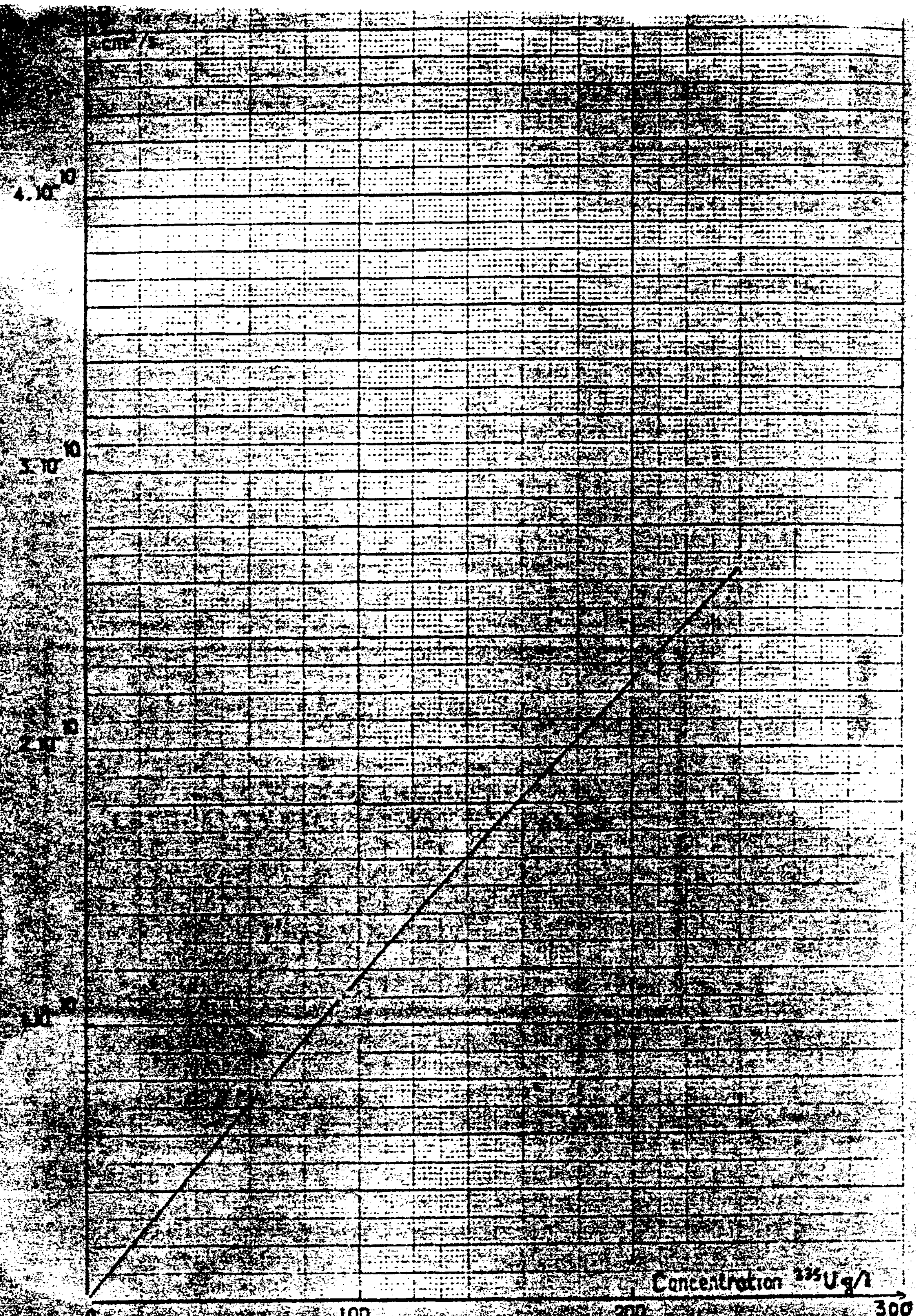
CALCUL DE L'EFFET DU MM $\frac{\Delta\rho}{\Delta H}$ EN PCM [illegible]

N° de manipulation	Concentration g/l U	H (cm)	T_2 (s)	ΔH [illegible]	[illegible]	Effet du MM en [illegible]
D4-01	[illegible]	[illegible]	35,6	[illegible]	[illegible]	0,1577
D5-01	[illegible]220	[illegible]	15,7	[illegible]	[illegible]	0,1590
D6-01	[illegible]	[illegible]	6,70	[illegible]	[illegible]	0,1600
D7-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1599
D1-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1599
D2-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1566
D3-02	[illegible]	[illegible]	5,61	[illegible]	[illegible]	0,1557
D1-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1150
D2-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1150
D3-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,1143
D1-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D2-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D3-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D1-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D2-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D3-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D1-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,0650
D2-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D3-06	[illegible]	[illegible]	4,96	[illegible]	[illegible]	[illegible]
D1-0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D2-0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D3-0[illegible]	[illegible]	[illegible]	6,76	[illegible]	[illegible]	[illegible]

[illegible]



- SILENE - Variation de l'effet du ... critique



SILENE : Variation du terme de freinage en fonction de la concentration en ^{235}U

(Shutdown Coefficient)

[illegible]

APPENDIX III

RAPPORT SRSC 93. 220 - Décembre 1993

A REVIEW OF THE SILENE CRITICALITY EXCURSIONS EXPERIMENTS

Francis Y. BARBRY

CEA INSTITUT DE PROTECTION ET DE SURETE NUCLEAIRE
DEPARTEMENT DE RECHERCHES EN SECURITE
SERVICE DE RECHERCHES EN SURETE ET CRITICITE
Centre d'Etudes de VALDUC - SRSC - 21120 Is-sur-Tille - France ☎ 80 23 40 [illegible]

A REVIEW OF THE SILENE

CRITICALITY EXCURSIONS EXPERIMENTS

Francis Y. Barbry
Institut de Protection et de Sûreté Nucléaire
CEA Valduc, 21120 Is-sur-Tille France
80 23 50 20

ABSTRACT

More than one thousand experiments reproducing criticality excursions in aqueous solutions of uranium highed enriched in ^{235}U have been conducted to date at VALDUC in the SILENE facility by the French Institute for Nuclear Safety and Protection (IPSN). This document summarizes results of selected experiments with reactivity insertions ranging from 4 cents up to 7 $. Valuable results relating to the first peak characteristics and integrated fissions yields provide reference data for evaluating and improving analytical models describing criticality excursions. In addition acquired knowledge is given concerning pressure increase, radiolytic gas formation and the general behaviour expected in the accidental situations which may occur in fuel cycle installations. The lessons drawn from those experiments concerning criticality accidents studies are given in this paper.

I. INTRODUCTION

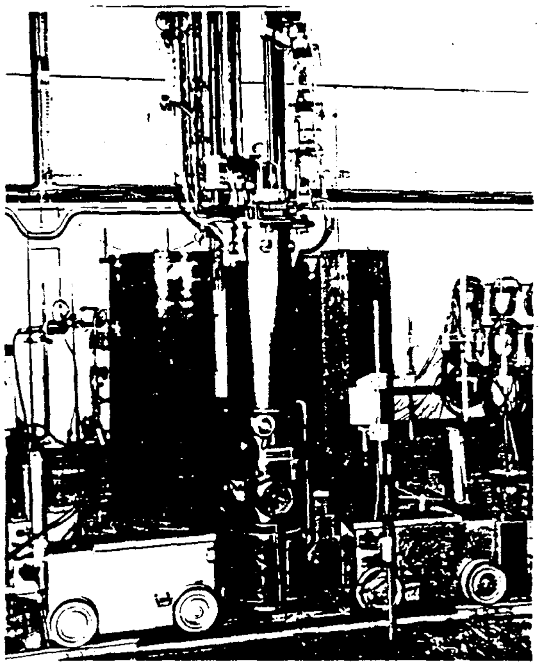
It is generally assumed that criticality accidents are most likely to occur during the processing of fissile solutions. So as to be able to cope with such an eventuality, the CEA has been engaged since 1967 in an important programme of criticality accident studies[1] using the CRAC facility[2] to begin with and at present since 1974 the SILENE reactor[3]. The general objective of the work undertaken at VALDUC is to study the phenomenology as well as the radiological consequences of an accidental criticality excursion so as to acquire, on the one hand, indispensable knowledge for criticality safety assessment and, on the other hand, to be in a position to define a protection and intervention policy.

II. DESCRIPTION OF THE SILENE FACILITY

SILENE is a homogeneous experimental reactor using a fissile solution of uranyl nitrate (U enriched in ^{235}U at 93 %) as fuel. The core is in the form of a small annular tank (36 cm diameter) located in the middle of a large concrete room referred to as the "cell". The fissile solution required for reactor operation of the reactor is prepared in a laboratory located in the cell basement[3]

The general operating principle of the reactor is as follows :

- The fissile solution, previously adjusted to SILENE operation concentration in a special large capacity tank, is pumped into the core up to a predetermined supercritical level. During this phase, a control rod is present in the core so as to avoid divergence.
- The "divergence" power excursion is then produced by withdrawing the rod from the core according to a procedure that depends on the selected operating mode for each experiment.
- When the experiment has been completed, the fissile solution containing the radioactive fission products is dumped into a tank located in a shielded room so as to allow quick access to the cell.



A ventilation circuit blows continuously through the upper part of the core so as to dilute the radiolysis gases that are formed. After the period required for their radioactive decay, these gases are removed through ad hoc filtration systems.

SILENE is designed to operate in three different modes depending on core reactivity, the control rod withdrawal rate and the presence or absence of an auxiliary neutron source.

. "PULSE" operation is obtained by the rapid removal of the control rod (at a rate of 0.2 or 2 $m.sec^{-1}$) with or without an additional source in order to obtain a very high power peak in a very short time (up to 1000 megawatts in a few milliseconds). With fast transients of this kind the reactivity is limited to 3.0 $.

. "FREE EVOLUTION" is achieved by slowly removing the control rod at speeds lower than 2 $cm.sec^{-1}$ with a neutron source. Reactivity cannot exceed 4 $ in normal operation but may reach 7 $ for solution "boiling" experiments. This mode simulates an accidental criticality excursion allowed to evolve freely.

. "STEADY-STATE" operation involves automatic control of the rod position, with very slow displacement rates (approx 2 $mm.sec^{-1}$) in order to maintain the reactor at a predetermined stable power level.

III. RESULTS

A. General behaviour of a criticality excursion in a solution

In general terms the development of an accidental criticality excursion in a solution is governed by the following principal parameters :

. the reactivity addition
. the initial neutrons source
. the effects due to the temperature, i.e.
  the nuclear temperature effect
  the expansion effect which brings about density variation of the medium as well as a "buckling" variation .
. the effects due to void ; this void arises in the first instance from the formation of bubbles of radiolytic gas, but void also occurs if boiling of the solution develops.

Once delayed critical is exceeded, a divergent chain reaction may be established leading to an exponential evolution of the power. This power excursion, whose kinetics is dependent on the reactivity input, is accompanied by the release of energy which is manifested mainly in thermal form. The heating of the fissile material results, on the neutronic side, in the appearance of feedback mechanisms. These feedback reactions overcome the current reactivity. The result is the appearance of a first power peak ; Figure 1 is a sketch of the result of a typical transient.

The first feedbacks to occur are due to the thermal expansion of the system and to the neutronic temperature effect. To these initial mechanisms arresting the chain reaction is added a second phenomena specific to solutions, the formation of radiolytic gas due to the decomposition of water along the length of the trajectories of the fission fragments. This second mechanism, due to voiding, supplements the first feedback reactivities which reduces the power level considerably. However, the radiolytic gas bubbles migrate towards the surface of the liquid, the accompanying reverse reactivity disappears and the power excursion starts again. It is this process of the appearance of gas, then the release out of the solution which is the origin of the power oscillations observed in the evolution of power. The essential difference which should be emphasized between the feedback mechanisms lies in the effect of the void formed by the radiolytic gas bubbles being a transitory effect, whilst the effect of the temperature, consequent on heating of the fissile solution, is permanent on the time scales being considered.

In certain cases the energy generated is sufficient to either bring the system to boiling, or produce a large pressure pulse resulting in significant equipment damage or solution dispersal.

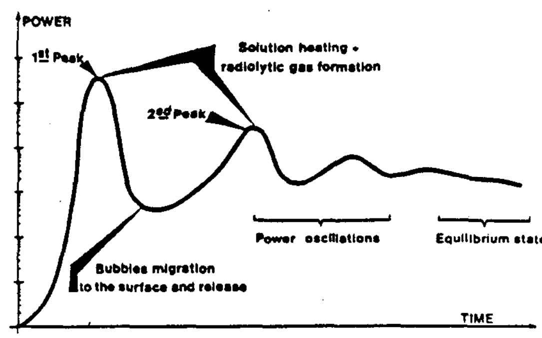


Figure 1 - Typical Criticality excursion

B. Results obtained at the 71 $g.l^{-1}$ concentration

The most representative results of the SILENE experiments in the unshielded configuration are reviewed in table I. The experiments have been classified into different categories :

. category 1 : reactivity steps below prompt criticality ($\rho < \beta$)
. category 2 : reactivity steps near prompt criticality ($\rho \# \beta$)
. category 3 : reactor "pulse" operation with large reactivity input ($\rho >> \beta$)
. category 4 : the same as category 3 but with presence of an external additional neutron source
. category 5 : reactivity ramps below solution boiling
. category 6 : large reactivity ramps ($\rho >> 4$ $) leading the solution to boiling
. category 7 : series of experiments performed with the same total potential reactivity but in various initial conditions

The effective reactivity at the first peak Δk_1 is calculated by the inhour equation and appropriate values of neutron lifetime and β_{eff}. The total potential reactivity Δkp is calculated by the Monte Carlo MORET code. The relation used between the K value and the solution height for the SILENE 71 $g.l^{-1}$ solution concentration is

$$K_{eff} = 0.68276 + 1.194\ 10^{-2} \times H - 9.905\ 10^{-5} \times H^2$$

. Neutronics data and symbols used

Lifetime of prompt neutrons at 71 g/l l = 36µs

GROUP	1	2	3	4	5	6
εi	1.28	1.24	1.26	1.23	1.26	1.20
βi	0.021	0.139	0.126	0.252	0.074	0.026
λi	0.0124	0.0305	0.111	0.301	1.13	3.0

$$\beta_{eff} = \sum_{i=1}^{6} \varepsilon_i \times \beta_i = 794\,pcm \qquad (pcm = 10^{-5})$$

Characteristics $Cu_t = 71.gl^{-1}$ Hc ≅ 37 cm					Results 1 st peak						Final		
Experiment n°	V_f l	Δkp $	Neutron Source	Duration s	T_2 s	Δk_1 $	$\dot{\mathcal{E}}$ fissions.s^{-1}	$\hat{\mathcal{E}}$ fissions	E_{p1} fissions	Δp bars	$\Delta\theta$ °C	N_F fissions	Category
LE3-229	36.1	0.035	yes	14400	235	0.035	$1.4\ 10^{12}$	$1.1\ 10^{15}$	-	-	1	$3.1\ 10^{15}$	1
LE1-214	36.9	0.14	yes	8000	44	0.14	$4.5\ 10^{13}$	$1.0\ 10^{16}$		-	4	$2.4\ 10^{16}$*	1
LE2-229	36.6	0.42	yes	14400	6.2	0.42	$7.1\ 10^{14}$	$1.9\ 10^{16}$		-	11	$7.5\ 10^{16}$*	1
S1-300	37.0	0.51	yes	1100	3.8	0.51	$1.3\ 10^{15}$	$2.2\ 10^{16}$	-	-	14	$6.5\ 10^{16}$	1
S2-300	37.7	0.97	no	260	0.13	0.97	$1.7\ 10^{16}$	$1.3\ 10^{16}$	$4.2\ 10^{16}$	-	22	$1.1\ 10^{17}$	2
S2-258	38.7	1.32	no	500	0.010	1.32	$7.1\ 10^{17}$	$1.8\ 10^{16}$	$4.5\ 10^{16}$	-	28	$1.5\ 10^{17}$	3
S3-258	39.3	1.84	no	420	0.0038	1.84	$4.9\ 10^{18}$	$5.4\ 10^{16}$	$8.1\ 10^{16}$	0.95	36	$1.9\ 10^{17}$	3
S4-258	39.7	2.14	no	420	0.0028	2.14	$9.1\ 10^{18}$	$7.0\ 10^{16}$	$1.0\ 10^{17}$	1.9	40	$2.3\ 10^{17}$	3
S2-259	40.1	2.60	no	420	0.00198	2.60	$1.7\ 10^{19}$	$8.2\ 10^{16}$	$1.3\ 10^{17}$	3.7	47	$2.7\ 10^{17}$	3
S3-259	40.5	2.86	no	420	0.00171	2.86	$2.1\ 10^{19}$	$7.9\ 10^{16}$	$1.4\ 10^{17}$	4.8	51	$2.9\ 10^{17}$	3
S4-346	40.2	3.0	no	180	0.00162	3.0	$2.4\ 10^{19}$	$9.8\ 10^{16}$	$1.5\ 10^{17}$	5.6	53	$2.9\ 10^{17}$	3.7
S1-362	40.9	3.0	yes	210	0.0039 (unstable)	1.79 ramp 3.4 $.$s^{-1}$	$5.3\ 10^{18}$	$5.6\ 10^{16}$	$8.5\ 10^{16}$	1.1	50	$2.8\ 10^{17}$	4.7
LE1-362	40.9	3.0	yes	700	0.136 (unstable)	0.95 ramp 0.036 $.$s^{-1}$	$2.0\ 10^{16}$	$9.6\ 10^{15}$	$4.1\ 10^{16}$	-	52	$3.1\ 10^{17}$	5.7
LE2-362	40.9	3.0	yes	210	0.025 (unstable)	1.12 ramp 0.18 $.$s^{-1}$	$1.8\ 10^{17}$	$1.2\ 10^{16}$	$4.5\ 10^{16}$	-	50	$2.8\ 10^{17}$	5.7
LE1-273	42.4	3.6	yes	1300	0.025 (unstable)	1.12 ramp 0.18 $.$s^{-1}$	$1.7\ 10^{17}$	$1.1\ 10^{16}$	$4.4\ 10^{16}$	-	63	$4.6\ 10^{17}$*	5
LE2-176	50.3	6.0	yes	900	0.018 (unstable)	1.17 ramp 0.18 $.$s^{-1}$	$4.1\ 10^{17}$	$1.7\ 10^{16}$	$3.7\ 10^{16}$	-	boiling	$7.4\ 10^{17}$	6
LE1-281	52.8	7.2	yes	600	0.017 (unstable)	1.18 ramp 0.18 $.$s^{-1}$	$4.2\ 10^{17}$	$1.7\ 10^{16}$	$3.8\ 10^{16}$	-	boiling	$8.6\ 10^{17}$	6

* Experiments lasting up to power restarting (post-accident phase)

Table I - SILENE data

ε_i	represents the efficiency of each group of delayed neutrons
C_{Ut}	Total uranium concentration (in $g.l^{-1}$) (93 % ^{235}U enriched uranium)
H_c	Delayed critical height (in cm)
V_f	Final volume (in liters)
N_f	Total number of fissions
Δkp	Total potential reactivity addition in the core
Δk_{eff_1}	Effective reactivity present at the first peak
$\Delta\theta$	Mean rise in temperature of the fissile solution at the end of the experiment (in °C), θ_i designating the initial temperature and θ_f the temperature reached at the equilibrium state t_e
T_2	Doubling time of power rise (in s)
ω	Reciprocal of period (in s^{-1})
$\dot{E}$	Maximum power at the top of the first peak (in fissions/s)
Δp	Dynamic pressure wave on the core tank bottom during the first peak (relative value in bars)
E_{p_1}	Energy integrated up to the botton of the first peak (in fissions)
$\hat{E}$	Total energy integrated up to the maximum of the peak power

The figures 2 to 5 illustrate the evolution of the power, energy and temperature during the experiments. Several typical excursions have been reproduced, namely :

- Figure 2 - A fast transient (S4-346) produced by a 3 \$ reactivity step and two intermediate transients (LE2-362 and LE1-362) resulting of reactivity ramps (0.17 and 0.035 \$. s^{-1}), all three experiments performed with exactly the same total reactivity excess.
- Figure 3 - A very slow transient (LE2-229 produced by a small reactivity addition (0.42 \$) but showing that, even in this case, a restarting must be expected.
- Figure 4 - An experiment (LE1-281) with a very large excess of reactivity ($\Delta k \cong 7.2$ \$) leading the solution to boiling.
- Figure 5 - Fast Transient 1st peak

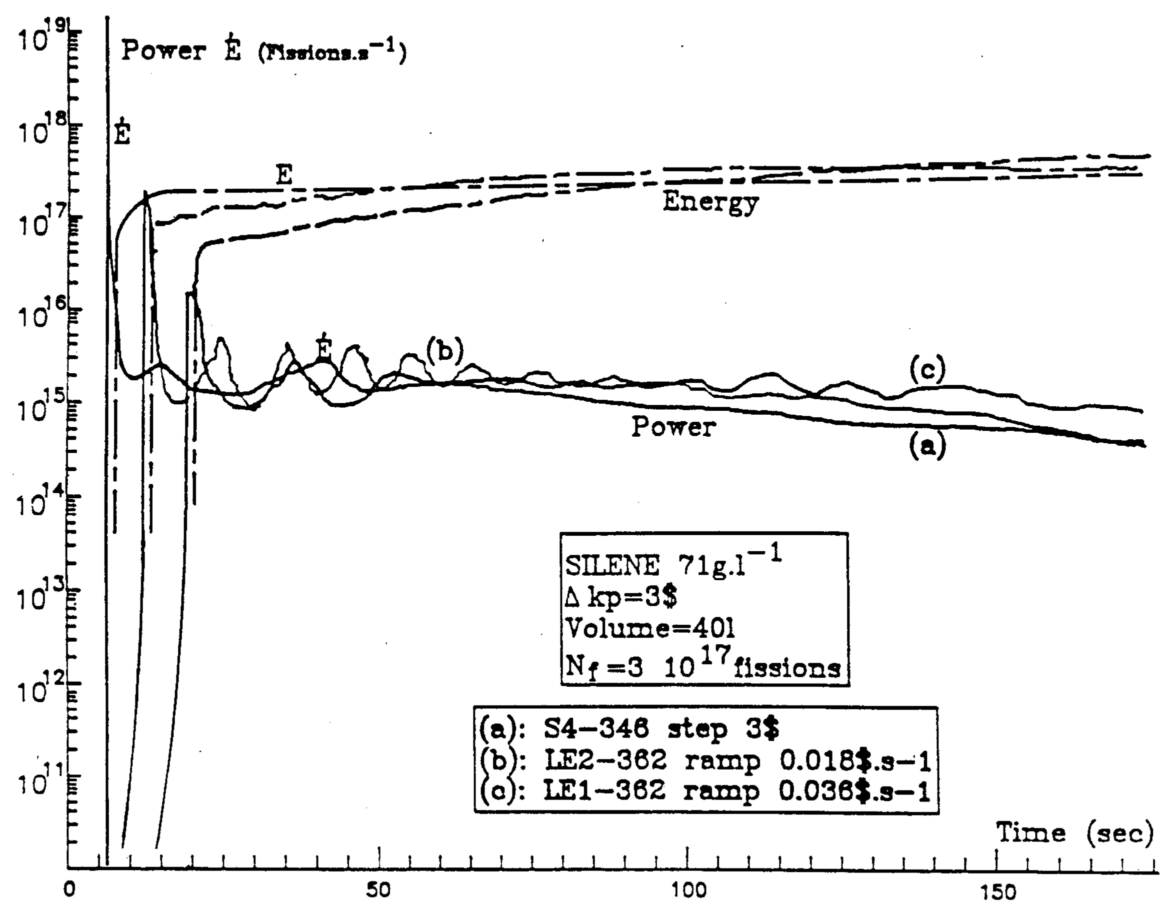


Figure 2 - Experiments Performed at the Same 3 \$ Total Reactivity

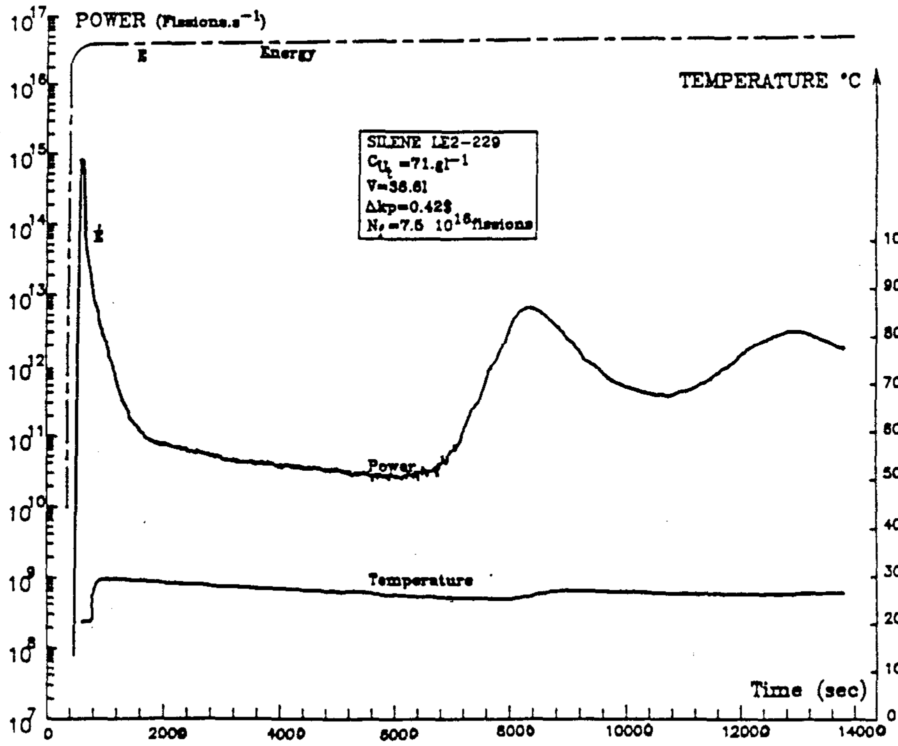


Figure 3 - Slow Kinetics Excursion with Power Restarting

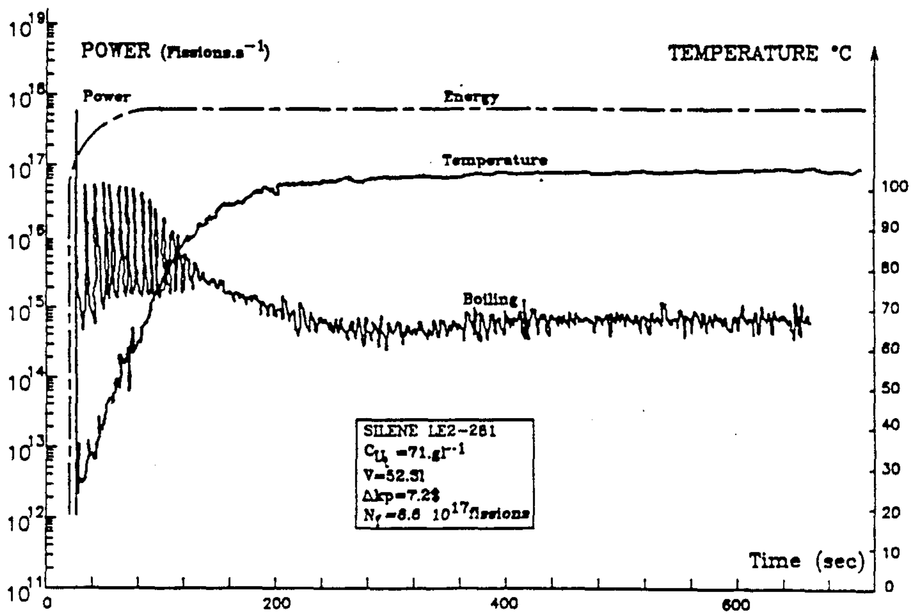


Figure 4 - Large Reactivity Insertion with Solution Boiling

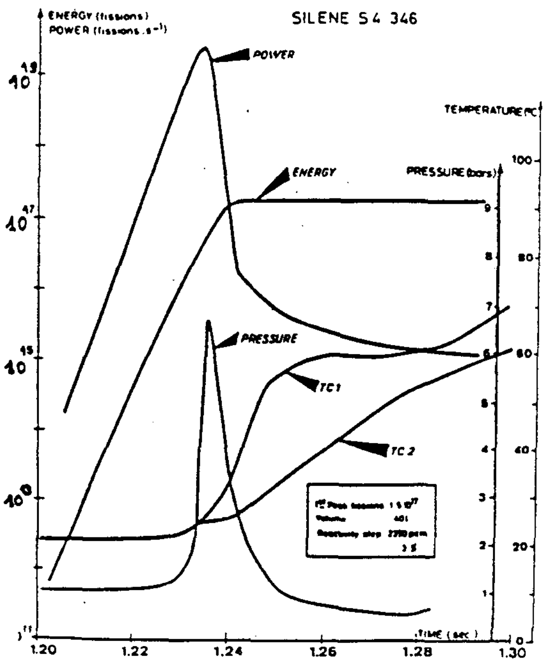


Figure 5 - Fast Transient 1st Peak

IV. KNOWLEDGE ACQUIRED

The lesson we have learnt here takes into consideration the overall results acquired during the CRAC and SILENE experiments, namely the 72 experiments conducted in the CRAC facility with a reactivity insertion obtained through continuous pumping of the solution into 30and 80 cm diameter cylindrical tanks and several hundred excursions performed with SILENE.

The range of the parameter and result variations were as follows :

- uranium concentrations between 20 and 340 g x l^{-1} (homogeneous configurations only)
- volume of fissile solution up to 250 liters
- total potential reactivity input ranging up to 10 \$
- reactivity ramps and "steps" reaching 2 \$ x s^{-1} and 3 \$ respectively
- presence or not of an additional neutron start-up source
- heating of the solution up to boiling

Our observations were :

- maximum power observed ≤ 10^{20} fissions x s^{-1}
- maximum total number of fissions ≤ 5 x 10^{18} fissions
- doubling time ranging from a few hundred µs to a few minutes

We can also mention other valuable information :

. Relation between N_f, V, Δk_p, t

For one configuration, namely a certain diameter ϕ of the vessel, it is possible to approximately relate the total specific fission yield during the chain of pulses to the potential reactivity Δk_p (except if boiling). The total number of fissions in the excursion normalized to the total volume of solution (hence to its heat capacity) fits an expression :

$$\frac{N_f\,(yield)}{total\ volume\ \ V} \cong k.\Delta k_p$$

k depends on the diameter of the vessel with
k # 3.4 10^{12} fissions.(p.c.m)$^{-1}$. l^{-1} for SILENE

. Relation between $\frac{N_f}{V}$ and t (ref.4)

From another standpoint, and this may useful for the accident estimation, it is possible using the maximum energies measured during CRAC and SILENE excursions up to 7 \$ reactivity insertion, to fit an empirical correlation between the specific total number of fissions $\frac{N_f}{V}$ (t) and the time as follows :

$$\frac{N_f}{V} = \frac{t}{3.55\ 10^{-15} + 6.38\ 10^{-17} \times t}$$

with t in seconds and V volume in liters

. Relation between the first peak power $\dot{E}$ and ω (fig 6)

For fast transients (ρ > β) the maximum specific peak-power $\dot{E}/V$ is varying with the reciprocal period ω as the following relation

$$\frac{\dot{E}}{V} = c^{te} \times \omega^{1,8}$$

. *Radiolytic gas formation*

The volume of radiolysis gas formed is proportional to the number of fissions[5] reaching approximately 1.1 x 10^{-13} cm^3/fission (i.e. 110 liters of gas for 10^{18} fissions). The threshold for the formation of radiolysis bubbles is estimated at 1.5 x 10^{15} fissions per liter of fissile solution.

. Pressure increase during the 1st peak

No significant overpressure was observed for doubling times T_2 greater than 10 ms but for very fast transients the energy generated and gas formed within the liquid may cause material ejection and some mechanical damage to the vessel (i.e. CRAC 44).

Dosimetry

A list of dosimetric measurements have been established[6]. It should be kept in mind that for different configurations the number of fissions is not proportional to the dose. The maximum value observed was 5.8×10^2 Gy at 1 m from the CRAC source for 10^{18} fissions.

. Solution boiling

The fissile solution is brought to its boiling point for a released energy level of about 0.33 MJ per liter ($\cong 1.1.\ 10^{16}$ fissions/l) and the boiling pseudo-plateau level depends on the excess of reactivity.

. Startup neutron source influence

The presence of an initial neutron source (external or intrinsic) strongly influence the behaviour of the excursion by the tendency to significantly delay the initiation of the burst when the source decreases. It results in a larger burst height because of a strong reactivity step in place of moderated reactivity ramps. It could be to recommanded to provide a neutron background in some processing operations when the internal source is weak to limit, in the case of an excursion, the size of the first peak and to maintain the resulting pressure below the level that would othervise result in significant equipment damage or solution dispersal.

. Post accident situation

Experiments carried out without solution dumping (See table I and Fig 3) show that in most cases of accidental situations the power excursion is likely to restart after a delay depending on heat transfers with the environment, unless some means of intervention has been prepared so as to stop the accident process.
Criticality accident detection systems, if designed for that purpose and this is the case for the French system, may be helpful in this kind of situation for providing information on the evalution of the post-accident phase and contribute to decision making, for example in the event of intervention.

V. CONCLUSION

The CRAC and SILENE criticality accident study programmes have provided a wealth of information on all the aspects of criticality excursions in aqueous fissile media : physics, dosimetry, detection, post-accident situation.

The practical lessons thus drawn will be helpful for evaluating and coping with the consequences of such an event. The accurate SILENE results will allow improvement of excursion modeling and new calculation code development [7,8]

The overall work will undoubtedly contribute to a better knowledge of the phenomena that may be encountered in accident situations and to the elaboration of a nuclear installation safety policy.

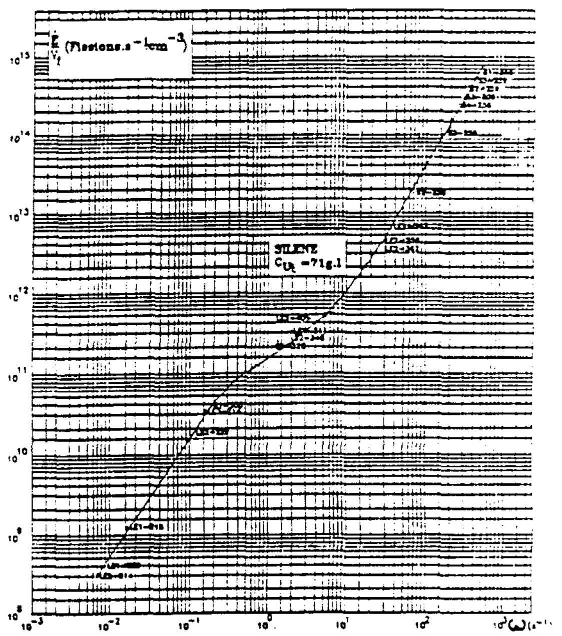


Figure 6 - Relation Beetwen the Specific Power and the Reciprocal Period

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