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OMPARISON REPORT ON OECD-CSNI LOCA STANDARD PROBLEM N° 7

Analysis of a Reflooding Experiment

by

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1 - INTRODUCTION

The seventh CSNI Standard Problem on LOCA is a separate effects experiment proposed by the French "Commissariat à l'Energie Atomique". For the first time the subject is the reflooding phase of the accident. It is based on an experiment performed on the ERSEC loop located at the Grenoble Nuclear Centre. This standard problem was a blind problem since the experimental results were not released before the deadline : March 15th 1979.

At this date contributions were received from 9 institutions of 8 member countries as listed below :

Country	Code	Contributer
AUSTRALIA	NAIAD	W.J. Turner (AAEC)
FINLAND	NORCOOL 1	J. Miettinen (TRCF)
FRANCE	RELAP mod 6	N. Tellier-M. Pichon (CEA-IPSN)
GERMANY GRS	REFLUX-GRS	A.B. Wahba
KWU	HYDROFLUT	Köhler
JAPAN	RELAP-REFLA	K. Sato (JAERI)
SWEDEN	RELAP mod 6	Jönsson, Rouhani et Gupta (STUDSVIK)
SWITZERLAND	RELAP mod 6	Aksan et Yanar (EIR)
UNITED STATES	RELAP mod 6	H.M. Delaney (EG & G)

Then one other contribution was submitted from NEDERLAND (ECN with REFLUX) ; 4 post test calculations have been made by :

FINLAND	RELAP 4 mod 6	H. Kantee and al (NORHAV)
GERMANY-GRS	REFLUX-GRS	A.B. Wahba
GERMANY-KWU	HYDROFLUT	Köhler
USA	RELAP 4 mod 6	C.A. Dobbe

2 - PROBLEM DESCRIPTION

Standard Problem n° 7 is one of the experiments performed on the ERSEC loop in Grenoble which is a facility used for the study of the heat transfer in the reflooding phase of the loss of Coolant Accident in PWR.

The test section consists of a tube uniformly heated by Joule effect and internally cooled (fig. 1). The tube is placed in a vacuum chamber with a reflecting shield in order to reduce heat losses in the high wall temperature region. The local heat flux corresponding to heat losses can be calculated with :

$$\phi_L(W/m^2) = 7300 \cdot \left[\left[\frac{Tw + 273}{1000}\right]^4 - 0.1\right]$$

where Tw is the local wall temperature (°C).

The initial conditions are :

Pressure : 3 bars

Wall temperature : 600°C (uniform)

Flooding rate : 52 kg/m^2 s (forced flow conditions)

Inlet Water subcooling : 23°C

Power generation : 6267.5 watts

The pressure, flooding rate, inlet water subcooling and power generation remain constant during the test.

The tube is made of Inconel 600 and its dimensions are :

- heated length : 3.325 m
- inner diameter : 12.10^{-3} m
- outer diameter : 14.10^{-3} m

The experimental results to be calculated are :

- wall temperature versus time for the following elevations : Z = 0.98 m - 1.3 m - 2.03 m - 2.99 m.
- quench time versus elevation.
- total pressure drop on heated length versus time.
- mass flow rate of entrained water versus time at the outlet of the test section.
- steam temperature versus time at the outlet of the test section.

3 - PRESENTATION OF THE PRETEST CALCULATIONS

Among the 10 pretest contributions to this Standard Problem, we can distinguish two kinds of results :

- those computed with RELAP 4 mod 6 (4 participants)
- those computed with other codes (6 participants).

So in addition to the individual comparisons, we made two general comparisons :

- one with the data obtained with RELAP 4 mod 6,
- one with the results obtained with other codes (NAIAD, NORCOOL 1, REFLUX, REFLUX-GRS, HYDROFLUT and RELAP-REFLA).

Figures 2 to 9 show the envelopes of all the predictions. As it can be seen these envelopes are large in any cases and surround the experimental results. For some of calculated results e.g. the mass flow rate of entrained water or wall temperature at 2.03 m elevation, one of the limits (upper in these cases) is not too far from the measured data.

3.1 - RELAP 4 mod 6 results

Figures 10 to 17 show the comparison of predictions with RELAP 4 mod 6. As it is a well known code, we will not describe it here [1]. The main options and parameters chosen by the different participants having used this code are given in the Table I. Though the parameters are not very different the calculated results are quite divergent. Some of these differences can be attributed to the choice of the numerical coupling of the liquid entrainment and vapor superheating models (see Appendix).

Turnaround temperature are well predicted by two participants for 1 m and 1.3 m elevations (fig. 10-11) but overpredicted (100°C to 150°C) for higher elevations (fig. 12-13). The two other participants always calculated too low temperatures (50°C to 100°C).

Every participant gave too short quench time (fig. 14).

The calculated pressure drop (fig. 15) is in any case very much higher than the measured data but this may be explained by the core volume model where exists a collapsed liquid region which gives a liquid density much higher than in the experiment where the void fraction under the quench front can be important.

The mass flow rate of entrained water at the outlet of the test section is given on fig. 16. The results are better and lie within a range of about + 10 %, - 40 % but the shape of the calculated results is not good for the first three hundred seconds where the entrained mass flow rate is underpredicted by all the participants. This result is consistent with the too high values of ΔP, the derivative of which gives, as a first approximation, the rate of stored water in the test section. We wonder why the participant who has the largest entrainment fraction (0.759) has the lowest mass flow rate.

The steam temperature is shown on fig. 17. Very large discrepancies are observed between the calculated results. Too high steam temperatures are not surprising due to the fact that no heat transfer between the steam and entrained water is taken into account in RELAP 4 mod 6.

3.2 - Results with other codes than RELAP 4 mod 6

These codes are :

- NAIAD (Australia, AAEC)
- NORCOOL 1 (Finland, TRCF)
- REFLUX/GRS (Germany, GRS)
- HYDROFLUT (Germany, KWU)
- RELAP-REFLA (Japan, JAERI)
- REFLUX (Nederland, ECN)

All these codes (except NAIAD) consider a non homogeneous flow in the continuous liquid phase region as well as in the continuous vapor phase region. Every code takes into account thermodynamic non-equilibrium in the dry zone. The comparison between calculated and experimental results is shown on figures 18 to 25.Similar to RELAP results,a wide divergence is observed on calculated wall temperature evolutions (fig. 18-21) : differences as large as 200°C are obtained on turnaround temperatures and 500 seconds on quench time for the 2 m. elevation. Nevertheless the results of two participants are in good agreement with measured data for turnaround temperatures (NORCOOL 1 and HYDROFLUT).

The calculated pressure drop is better than with RELAP (fig. 23) but NAIAD and NORECOOL 1 give very low values.

The entrained mass flow rate (fig. 24) is rather good, excepted the very low prediction of NORCOOL 1.

Despite the fact that all these codes include heat transfer between steam and entrained water in the dry region, the steam temperature predictions are not better than those given by simpler models like those in RELAP 4 mod 6.

4 - DISCUSSION ON INDIVIDUAL RESULTS

4.1 - Australia

NAIAD code considers an homogeneous flow and a thermal equilibrium in the continuous liquid phase as well as in the continuous vapour phase region.

In the dry region heat transfer is given by a modified Ellion correlation (Andreoni correlation) and steam temperature is obtained from this calculated heat flux with the help of Beattie's model in a separate calculation.

The quench front model is the well known Yu-Coney-Farmer's model which requires the use of the wall temperature near the quench front which is difficult to determine.

We see on fig. 18-21 that if wall temperature are overpredicted at low elevations (1 and 1.3 m) rather good results are obtained in the upper part of the test section.

Quench time (fig. 22) is too high mainly at high elevations.

As already said, and as a consequence of the homogeneous flow assumption the pressure drop is underpredicted (fig. 23). On the other hand, the entrained mass flow rate (fig. 24) has the highest value among the non RELAP results and steam superheat is too high (fig. 25).

4.2 - Finland

Finland performed their calculation with NORCOOL 1. The main features of NORCOOL 1 are :

- two phase flow : quasi steady state and drift flux model below the two phase level and the two phases heated separately above this level. The fraction of entrained water is determined by a critical Weber number, by a minimum entrained droplet size calculated by a force balance on a drop and by a given size distribution.

- heat transfer : inverted annular flow, dispersed flow and steam flow are considered. A two-step model is used in dispersed flow which allows thermal equilibrium : the walls transfer heat to vapor (by convection and radiation), to droplets (radiation) while vaporization or condensation is possible at the steam and droplets interfacial area (heat transfer outside and inside the droplets).

- quench front model : an analytical rewetting correlation based on a two region model is used and said suitable for one and two dimensional cases.

This code performed one of the best turnaround temperature calculation especially in the upper part of the test section but this result is rather surprising if we consider other parameters : total pressure drop and entrained mass flow rate are about one half of the experimental values. Nevertheless the quench time is only slightly underpredicted.

4.3 - France

The results were performed with RELAP 4 mod 6 [3] . Without any personal experience with this code the user guideline and a FLECHT test at 3 bars data set were used to determine the input parameters. These parameters are resumed in Table I. Without taking heat losses into account the calculated wall temperatures should have been higher than the experimental ones but this is not true for the two lowest thermocouples. The quench time is always under-predicted except for the highest elevation where prediction is good.

The entrained mass flow rate compares rather well with the measured data except in the beginning of reflooding where the RELAP 4 mod 6 entrainment model does not allow to represent the experimental mass flow rate overshoot. With this model the selected maximum entrainment fraction of 0.68 seems to be good at 3 bars. The pressure drop across the heated tube (fig. 47) is much higher than the measured data but this fact may be explained by the model which does not allow to have a void fraction in the liquid under the quenching front.

4.4 - Germany - GRS

GRS performs reflooding calculations with REFLUX/GRS Code.

. A non homogeneous two phase flow is considered in the continuous liquid phase through a drift flux model while a bubble rise model is used to calculate the swell level. In dispersed flow the carryover criterion of Plummer is used with a critical Weber number of 1.5. Droplets are allowed to break up until a diameter of 1 mm.

. Inverted annular flow, dispersed flow and steam flow are considered for heat transfer. A two step model describes the different kinds of heat transfer in dispersed flow : wall to vapor (modified Mac Adams), wall to liquid (Forslund or Groeneveld, depending on the wall temperature) and vapor to liquid (Lee-Ryley type correlation).
The radiative heat transfer is assumed to have three components according to the Sun, Gonzalez and Tien model.

. Quench front progression is calculated with the one dimensional model of FLUT and a rewetting temperature which depends on pressure and local subcooling.

Good predictions of turnaround temperature are observed if we except the top of the test section where an overprediction of about 100°C is calculated.

If we except the first 75 seconds where the prediction is good, quench time is too short and the quench front velocity does not depend on elevation in the last two meters of the test section.

The shape of the pressure drop curve is well-predicted although a fast increase is observed in the beginning of reflooding ; about the same time the entrained water is too low and as a consequence the calculated steam temperature is too high.

4.5 - Germany - KWU

HYDROFLUT is the code used by KWU for this exercise.

. The hydraulics model accounts for non homogeneous flow both in the continuous liquid region where the drift flux model is used (with an initial drift velocity given by KWU's single tube reflood experiment) and in the dispersed flow where a slip correlation versus quality is introduced.
Plummer's model is used for carryover but with a $W_{ec} = 1$ and droplets can be entrained before $G_{vapor} = G_{crit}$. We note that this point is very consistent with our experimental observations.

. Heat transfer in the inverted annular flow uses the classical Bromley correlation but subcooling is taken into account. In dispersed flow, saturated droplets receive heat from walls (radiative and Bromley type transfer) and vapor, while vapor is heated by radiation and convection (Dittus-Boelter). Nothing is said about the involved radiative model.

. Quench front progression is calculated with one dimensional Yamanouchi's type model with a Leidenfrost temperature depending on pressure and subcooling.

On fig. 18 to 21 we can see the computed wall temperatures in two cases (new tube and oxidized tube) : the shape of these curves is very similar to the experimental one and if turnaround temperatures are underpredicted for the two first elevations, a good and a very good result is obtained for 2.3 and 3 m. elevations. Quench velocity in given conditions is well known to be dependent on the presence, or not, of an oxide layer (nature and thickness). The quench time computed values for the case of a new test section are higher than those for an oxidized one, which is consistent with experimental results. But, although the test section for the CSNI exercise was quite oxidized, the calculated results which are in good agreement with the measured data are those corresponding to a new tube. The calculated quench time for an oxidized wall is very good up to 1.3 m elevation and widely underpredicted after.

The flow rate of entrained water is well calculated with, however, 10 to 20 % overprediction between 300 and 500 seconds. Steam temperature on the other hand, is 150 to 200°C higher than the experimental result. Pressure drop is not calculated.

4.6 - Japan

The calculation was made using RELAP-REFLA code which has been developed from the loop analysis code RELAP 4-FLOOD and the reflood computer

program Refla 1D. Fig. 18 to 21 show that wall temperature is widely underpredicted for any elevations, as well as quench time. Pressure drop and steam temperature at the outlet of the test section are too high while entrained mass flow rate is rather good after the first 50 seconds, where overperdicted values are calculated.

4.7 - Nederland

The original version of REFLUX (MIT) was used to calculate this reflood test.

Generally wall temperature is overpredicted which is consistent with the fact that the flow rate of entrained water is too small and radiation is not accounted for.

Quench time is very high (no model for quench front progression, but a quench temperature) and it's difficult to explain in these conditions why the total pressure drop is well calculated.

Steam temperature is good too.

4.8 - Sweden

RELAP 4 mod 6 was used to perform the calculations with the best estimate reflood options. These options are resumed in Table I. Though these options are nearly the same as the other RELAP calculations it gives a much faster reflooding (fig. 10 to 14). The numerical coupling of the liquid entrainment and vapor superheating models seems to be implicated in these results.* Besides the quench time which is too short (three times shorter than the experimental values at 3 m.) the turnaround temperature is underpredicted for any elevation. There is a contradiction with the maximum entrainment fraction (0.759) which is higher than with other RELAP calculation and with the mass flow rate of entrained water which is the lowest one (fig. 16) of all RELAP calculations.

4.9 - Switzerland

The computations were performed with RELAP 4 mod 6 and the main selected options are given in Table I. The main difference with other RELAP 4 mod 6 computations is the choice of parameters in the dispersed flow heat transfer correlation :

$$h = (\text{Modified HSU + Bromley-Pomeranz})\ (1-Z^n) + (\text{Dougall-Rohsenow})Z^m$$

The selected parameter for Z was the quality and the exponent n is 0.33 ; the other participants have selected the void fraction to the exponent 30.

The turnaround temperatures are underpredicted and it is not clear why the quench time is so low in comparison with the results of other RELAP 4's users.

4.10 - United States

The predictions were made with RELAP 4 mod 6 and the main selected options are given on Table I. These options are quite similar to those of France with two exceptions : the simulation of heat losses and the dispersed

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*See Appendix

flow heat transfer. However, these two differences do not give consistent results : the simulation of heat losses should have given lower temperatures which is not the case (fig. 12-13) and the sum of Bromley and HSU heat transfer correlation (instead of intersection of Bromley and HSU) should have given lower quench time which is not verified too (fig. 14). The calculated pressure drop across the heated tube is lower than with other RELAP 4 mod 6 calculations and does not seem to follow the collapsed level history. Quench time evolution is quite the same as French results.

5 - OPTIONAL EXERCISE : same conditions but P = 1 bar.

This pressure is rather unrealistic and may be, this explains that only four countries (Australia, Germany-KWU, Japan and USA) give an answer. Indeed the interest of this facultative problem lies especially in testing the pressure range within which the reflooding models are suitable.

Results are shown on Table II.

a) General comments :

- Quench time : all calculated values are shorter than the experimental ones, Australian results being the best with a no more deviation than 20 % while Japanese results lie between the fourth and the fifth of the experimental quench time.

- Turnaround temperature : All results exhibit the same trend, with a too large increase of turnaround temperature with elevation : good (KWU, Australia) or low (USA - Japan) temperatures at low elevations and overpredicted values at high elevations, the envelope of results being given by KWU and Japan.

- Turnaround time : Wall temperature curves are very flat and then turnaround time is of low interest.

b) Comparison 1 bar/3 bars :

Australian, German (KWU) and Japanese results at 1 bar are consistent with results at 3 bars : quench time and turnaround temperature are increased when pressure is decreased. For USA, this is only true for 2 and 3 m elevations : quench time is shorter at 1 m and turnaround temperatures are lower at 1 and 1.3 m.

It is interesting to analyse and compare the deviations between calculated and measured data for 1 and 3 bars in order to evaluate how well (or not) pressure effect is taken into account in the calculations.

The Table III indicates versus elevation and pressure the algebraic deviation of computed quench times and turnaround temperatures in comparison with experimental values. Participants results which have not performed the 1 bar exercise are also included.

Some observations have to be made :

- with Naïad, if the observed deviation on turnaround temperature has the same order of magnitude and the same sign, on the other hand quench time which is widely overpredicted at 3 bars is too low at 1 bar.

- for Hydroflut, quench time deviation is quite the same whatever the pressure can be, but turnaround temperatures which are well predicted at 3 bars are too high, especially in the upper part of the tube at 1 bar.

No particular comment on Refla and Relap-USA calculations which give deviations which are about the same at 1 and 3 bars.

6 - POST TEST CALCULATIONS

6.1 - USA

The sum of Bromley and HSU heat transfer correlations was replaced by their intersection and the void fraction weighting factor by a quality weighting factor in the dispersed flow regime.

These modifications did not improve the calculated results : entrained mass flow rate is not significantly modified (fig. 31), turnaround temperatures which were overpredicted in the upper part of the test section in the pre-test calculation became underpredicted in the post-test calculation. Quench time is not modified at low elevations but is strongly increased at high elevations (fig. 28 - 29).

6.2 - Finland

Finland performed a post-test calculation with RELAP 4 mod 6 but before fixing the parameters and options a parametric study was done. The set of options and parameters which gave the best results are :

weighting parameter	void fraction
exponent	20
numerical coupling of the liquid entrainment and vapor superheating models	explicit
HSU and BROMLEY	addition
entrainment correlation	STEEN-WALLIS
maximum entrainment fraction	varied during the transient between 0.82 to 0.5

From the comparison with the US pre-test calculation which followed the former recommended guidelines for options the underneath comments can be made :

- The turnaround temperatures are reduced and this leads to underprediction at low elevations and a smaller overprediction at higher elevations (fig. 26 - 29).

- The quench time is slightly improved (fig. 30).

- The shape as well as the magnitude of the entrained mass flow rate is better due to the reduction of the maximum entrainment fraction versus time.

6.3 - Germany-GRS

The only modification in the REFLUX-GRS code is the wall temperature just above the quench front in the DUFFEY-PORTHOUSE correlation.

As a result the quench front velocity is significantly improved (fig. 36), but the maximum wall temperature and the steam temperature at the outlet of the test section remain practically inchanged (fig. 32 - 39).

6.4 - Germany-KWU

The experimental quench time propagation is well fitted by reducing the heat release on the HYDROFLUT quench front model.

This improvement does not modify the turnaround temperature and has a slight effect on steam temperature and entrained mass flow rate (fig. 38 - 39).

7 - CONCLUSION

This exercise was a test to assess the capability of various codes to predict the thermal behaviour during reflooding in a simple test section with given boundary and initial conditions, and also a way to check how the physics of thermal-hydraulic phenomena involved during reflooding are handled in these codes.

From the analysis of the results the following comments can be made :

7.1 - Turnaround temperatures (3 bars exercise) :

- all the results lie within a range of about ± 15 %. This maximum deviation of calculated values in comparison with experimental ones is not very large if we remember that two phase flow heat transfer correlations and models are generally considered reasonable when they work with this accuracy.

- however, due to the high temperature level encountered, a deviation of 15 % leads to absolute errors which may be very high (here 100 to 150°C). Such errors sometimes cause problems especially when they correspond to under-predicted temperatures (Japan, Sweden, Switzerland).

- some computed values are very close to measured data (Hydroflut and at a a lesser degree Norcool, Naïad and Reflux-GRS) and this is in some cases surprising if we consider the large discrepancies which occur sometimes with regard to quench time (see 7-2) and heat partition.

7.2 - Quench time (3 bars exercise) :

Quench front velocity is an important parameter for both the evolution of wall temperatures in the dry region, and clad oxidation which depends on temperature and time.

In the pretest calculations quench front propagation is not generally well described. In fact discrepancies as large as 80 % (RELAP-REFLA, RELAP 4 MOD 6 - Swedish calculations) were observed. In some cases codes which predict with a reasonable accuracy the turnaround temperatures can produce bad quench times (Naïad : + 60 %).

Improvements were obtained in the post test calculations by changing some parameters in the quench front model (Reflux-GRS, Hydroflut) or adjusting step by step the maximum entrainment fraction (RELAP 4 MOD 6 - Finnish calculations). However one might ask if such modifications would be adequat for other reflooding conditions than those which are considered here.

7.3 - Pressure drop

The pressure drop in the test section is not generally well predicted especially in the RELAP 4 MOD 6 calculations and this is an area where improvements are necessary due to the strong effect of the core total pressure drop on the system behaviour.

7.4 - Pressure effect

Though the calculations performed for the test at 1 bar were of low practical interest, they showed that the effect of pressure is not well taken into account by the four participants in this optional exercise. (table III)

7.5 - Codes

All the codes other than RELAP 4 MOD 6 and NAIAD consider a non homogeneous flow both in the continuous liquid and continuous vapor regions, and take into account thermal non-equilibrium in the dry zone. Despite this effort in the description of the physical phenomena, it appears that the results considered as a whole are not much better than the results obtained using RELAP 4 MOD 6, at least for wall temperatures and quench time. However the best predictions can be attributed to codes other than RELAP partly due to better physics and partly due to the fact that RELAP was adjusted from bundle experiments with cosine axial power and grids effects while some other codes were adjusted from single tube experiments (Hydroflut).

As far as RELAP 4 MOD 6 is concerned the best results were obtained with the explicit coupling of the liquid entrainment and vapor superheating models and void fraction as the weighting parameter in the dispersed flow heat transfer. Some divergencies between results were not clearly explained and may come from differences between versions of RELAP 4 MOD 6.

7.6 - Conclusions and recommendations of the Workshop on ISP7 :

- As had been anticipated when selecting this problem, the codes utilising thermal equilibrium assumptions could not be made to fit the results of ISP 7 in all respects. The reflood experiment includes very strong non-equilibrium effects. For example, subcooled boiling or void formation modelling contributed to significant divergence between the calculated and measured channel pressure drop.

- RELAP 4/MOD 6 incorporates empiricisms taken from a large number of bundle reflood tests and it is considered that this is an important cause for the discrepancies observed in the prediction of this monotube experiment.

- ISP 7 results are therefore not sufficiently conclusive with respect to the achievable accuracy of best estimate calculations describing system behaviour. Codes designed to describe the quench front in more detail generally performed better than RELAP codes.

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[9] RELAP 4 mod 6 - Calculations on the 7th CSNI Standard Problem concerning a separate effect test for reflooding by H. Kantee, J. Miettinen, H. Ollikkala. NORHAV, Finland.

[10] NORCOOL 1. Calculations on CSNI LOCA Standard Problem n° 7 by J. Miettinen NORHAV, Finland.

APPENDIX

Considering the large discrepancies between the RELAP 4 mod 6 calculations we tried to determine the influence of the numerical coupling of the liquid entrainment and vapor superheating models.

Two computations were performed using each a different option : explicit or implicit method ; every thing being equal for the other options.

The results are given on fig. 40-41 where are shown the evolutions of quench time versus elevation and mixture level versus time.

We can see that these two methods give quite different transient solutions and do not converge to the same solution, the explicit one being better (compared to the measured data) than the implicit method for the given exercise.

TABLE I

COUNTRY	FRANCE	SWEDEN	SWITZERLAND	UNITED STATES
modelisation of the inner cooled tube	rectangular geometry	cylindrical geometry externally cooled	cylindrical geometry	cylindrical geometry externally cooled
Heat losses taken into account	No	Yes by simulation of two fictitious layers	No	Yes update of the code
Number of heat slabs	20	14 (inequal)	20	20
Moving mesh	Yes	Yes	Yes	Yes
Heat transfer correlations	HTS 4 (with intersection of Bromley and HSU)	HTS 4 (with Bromley + HSU)	HTS 4 (with Bromley + HSU)	HTS 4 (with Bromley + HSU)
Core Super heat model	Yes	Yes	Yes	Yes
Energy partitioning	calculated by the code	calculated by the code	calculated by the code	calculated by the code
Dispersed flow weighting parameter	void fraction	void fraction	quality	void fraction
Liquid portion of the weighting function exponent	30	30	0.33	30
Entrainment correlation	Steen-Wallis	Steen-Wallis	Steen-Wallis	Steen-Wallis
Maximum entrainment fraction	0.68	0.759	0.7	0.68
Modified bubble rise	Yes	Yes	Yes	Yes
HSU exponent	calculated by the code	calculated by the code	0.0076	calculated by the code
Numerical coupling of the liquid entrainment and vapor superheating models	explicit	implicit	explicit	explicit
Time steps	$t \leq .2$ $\Delta t = 0.1$ $t > .2$ $.001 < \Delta t < .2$	$t<2.10^{-5}$ $\Delta t = 10^{-5}$ $2.10^{-5}<t<.4$ $10^{-3}<\Delta t<10^{-2}$ $.4 <t< 2$ $2.10^{-3}<\Delta t<2.10^{-2}$ $2. <t<20.$ $10^{-2}<\Delta t<5.10^{-2}$ $20. <t<400.$ $10^{-2}<\Delta t<0.1$	$0<t<0.2$ $10^{-3} < \Delta t < 10^{-2}$ $0.2 <t < 1000$ $10^{-3} < \Delta t <.2$	$t<.2$ $\Delta t = 0.1$ $t>.2$ $10^{-3}<\Delta t<.2$

	P = 1 bar	0.98 m	1.30 m	2.03 m	2.99 m
Japan	a) : Turnaround temperature (°C)	675	712	822	943
	b) : Time of turnaround (s)	55	78	95	127
	c) : Quench time (s)	117.5	170	315	?
U S A	a	650	725	905	1040
	b	40	90	170	220
	c	100	225	625	960
Australia	a	860	895	946	985
	b				
	c	465	625	980	1445
K W U	a	800	892	1024	1152
	b				
	c	404	572	840	1060
Experience	a	815	833	860	865
	b	125	212	200	150
	c	585	800	1105	1315

TABLE II

		Quench time		Turnaround temperature	
Participant	Elevation m	1 bar	3 bars	1 bar	3 bars
Australia (Naïad)	1	- 21 %	+ 60 %	+ 6 %	+ 15 %
	1.3	- 22 %	+ 40 %	+ 7 %	+ 7 %
	2	- 12 %	+ 36 %	+ 12 %	+ 6 %
	3	+ 10 %	+ 60 %	+ 14 %	+ 3 %
Germany-KWU (Hydroflut)	1	- 30 %	- 10 %	- 2 %	- 5 %
	1.3	- 30 %	0 %	+ 6 %	- 6 %
	2	- 24 %	- 20 %	+ 20 %	- 3 %
	3	- 20 %	- 30 %	+ 33 %	0
Japan (Refla)	1	- 80 %	- 65 %	- 18 %	- 7 %
	1.3	- 80 %	- 75 %	- 14 %	- 15 %
	2	- 72 %	- 55 %	- 2 %	- 16 %
	3	?	?	+ 9 %	- 13 %
U S A (Relap)	1	- 83 %	- 60 %	- 21 %	+ 1 %
	1.3	- 72 %	- 67 %	- 13 %	- 1 %
	2	- 43 %	- 18 %	+ 7 %	+ 10 %
	3	- 27 %	+ 4 %	+ 22 %	+ 16 %
France	1		- 52 %		+ 4 %
	1.3		- 51 %		- 1 %
	2		- 42 %		+ 7 %
	3		+ 2 %		+ 16 %
Switzerland	1		- 65 %		- 7 %
	1.3		- 65 %		- 16 %
	2		- 59 %		- 17 %
	3		- 44 %		- 15 %
Sweden	1		- 87 %		- 8 %
	1.3		- 88 %		- 14 %
	2		- 86 %		- 14 %
	3		- 76 %		- 13 %
Germany-GRS	1		- 41 %		+ 5 %
	1.3		- 37 %		0
	2		- 26 %		+ 6 %
	3		- 5 %		+ 13 %
Finland	1		- 13 %		+ 11 %
	1.3		- 19 %		+ 3 %
	2		- 20 %		+ 2 %
	3		?		+ 2 %

TABLE III

Country	Computer	Numerical Method	Time Steps	Computation time/Real time
Australia	IBM 3031			0.15 CPU/s
Finland				
France	CDC 7600	Implicit explicit in the core superheat coupling	$t < .2$ $\quad \Delta t = .01$ $t > .2$ $\quad 10^{-3} < \Delta t < .2$	0.57 CPU/s
Germany-GRS	AM DAHL 470/V5	Implicit	Hydraulic : $\Delta t = 1.$ Thermodynamic : micro time steps	5. CPU/s
Germany-KWU	CDC-CYBER 176	Implicit	$\Delta t = 1$	0.025 CPU/s (?)
Japan				
Sweden		Implicit	$t < 2.10^{-5}$ $\quad \Delta t = 10^{-5}$ $2.10^{-5} < t < .4$ $\quad 10^{-3} < \Delta t < 10^{-2}$ $.4 < t < 20$ $\quad 2.10^{-3} < \Delta t < 2.10^{-2}$ $2. < t < 20.$ $\quad 10^{-2} < \Delta t < 5.10^{-2}$ $20. < t < 400.$ $\quad 10^{-2} < \Delta t < 0.1$	
Switzerland		Implicit	$+ < .2\ 10^{-3} < \Delta t < 10^{-2}$	
U S A		Implicit explicit in the core superheat coupling	$t < .2$ $\quad \Delta t = .01$ $t > .2$ $\quad 10^{-3} < \Delta t < .2$	

TABLE IV

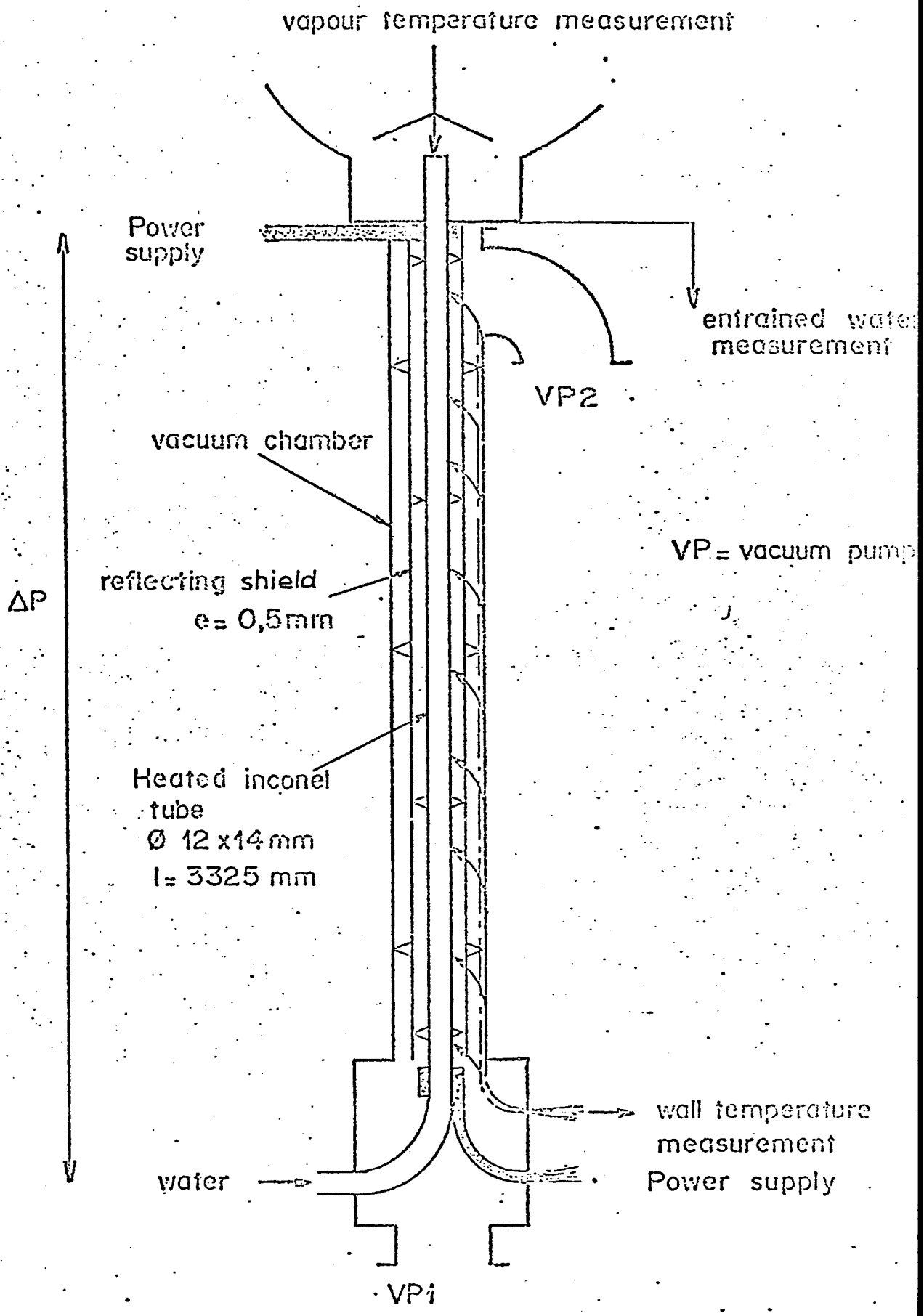
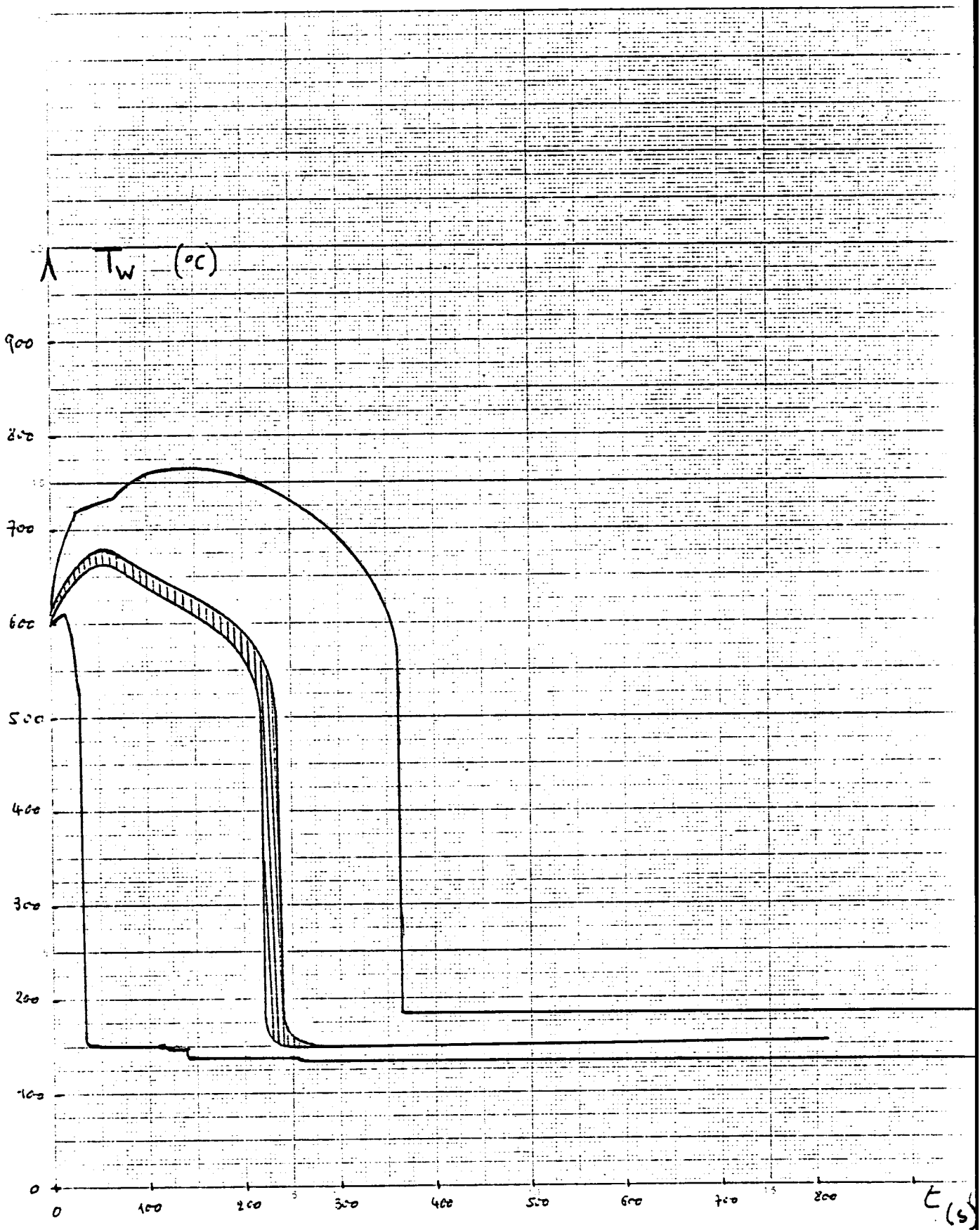
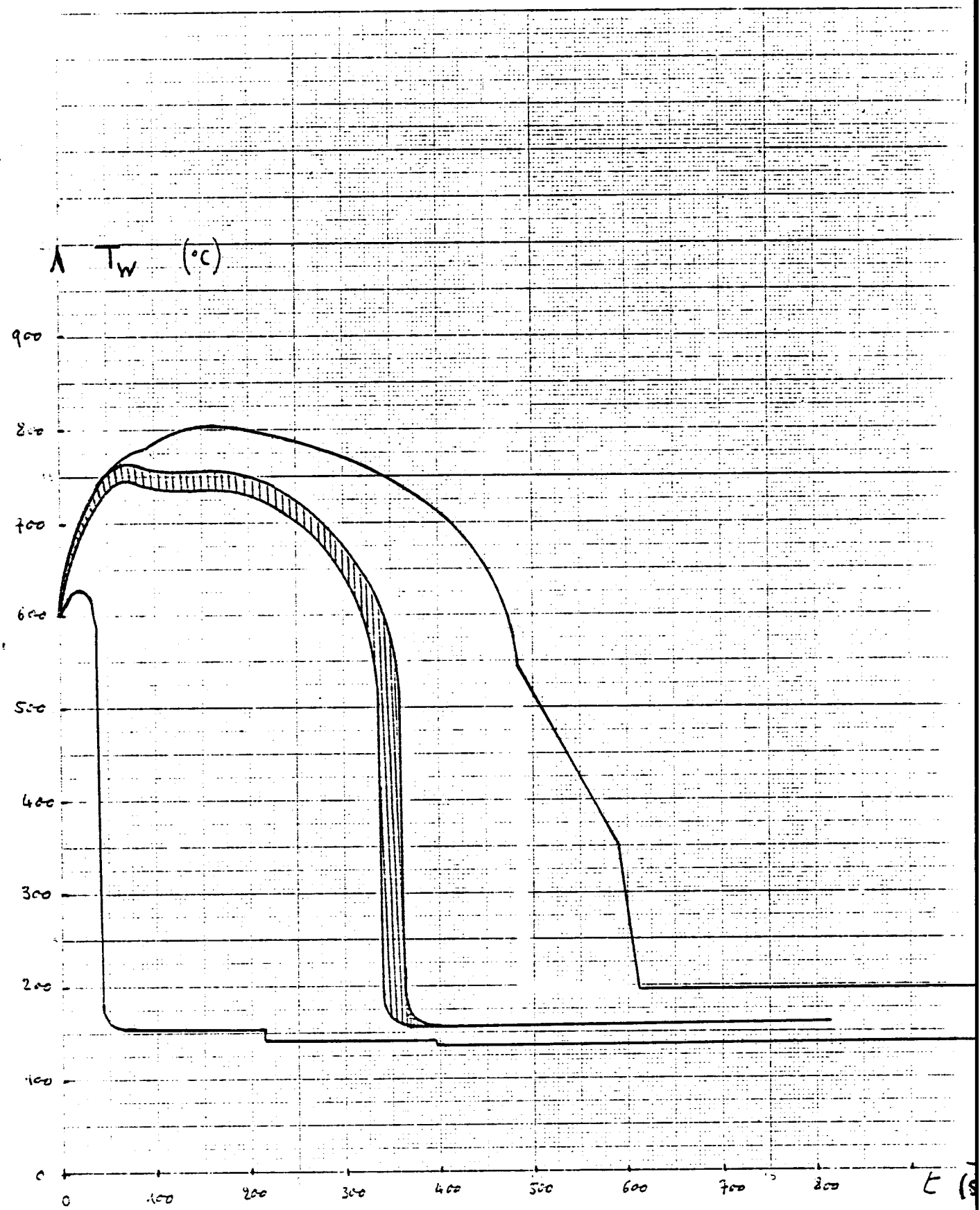


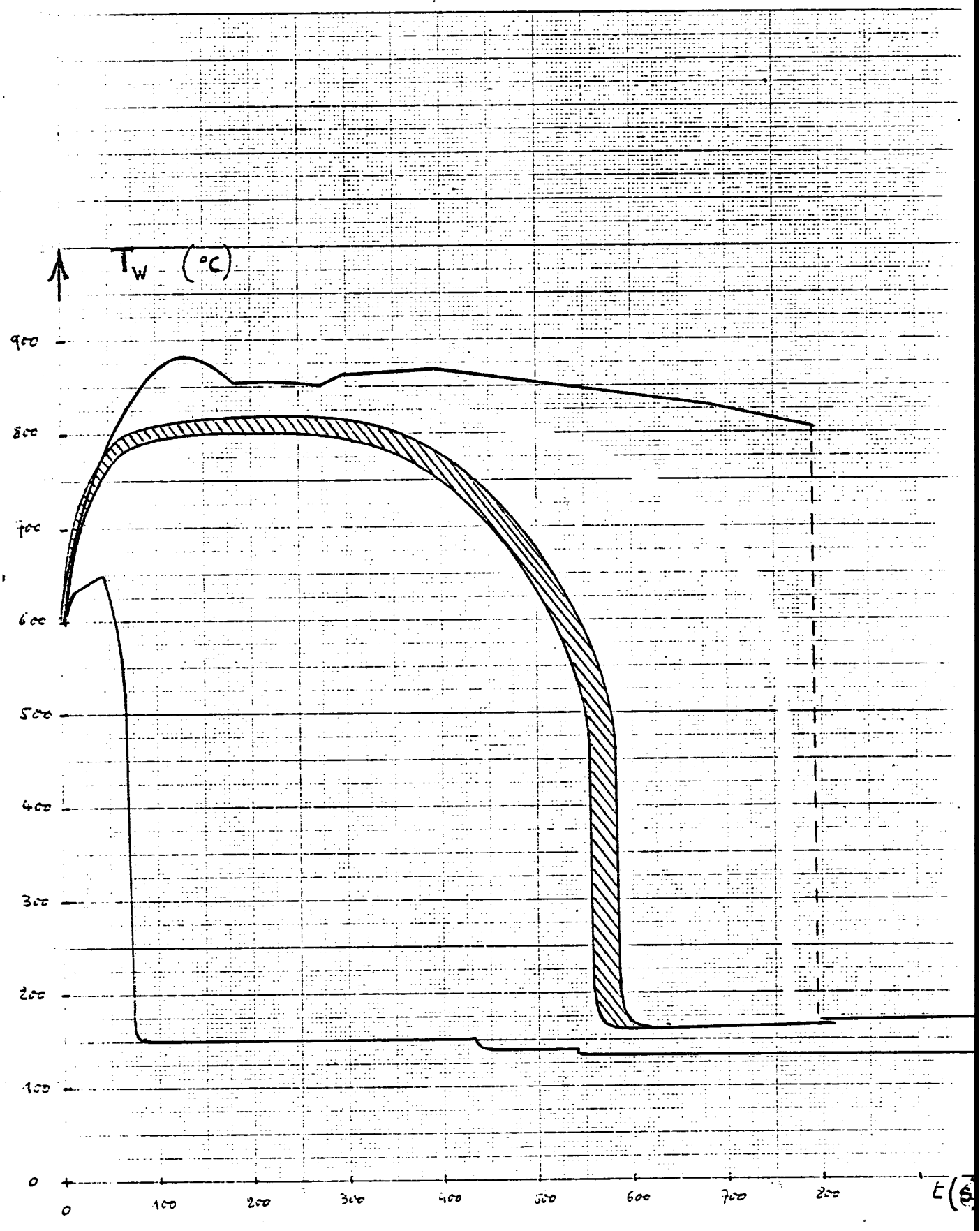
Fig. 1. Scheme of test section



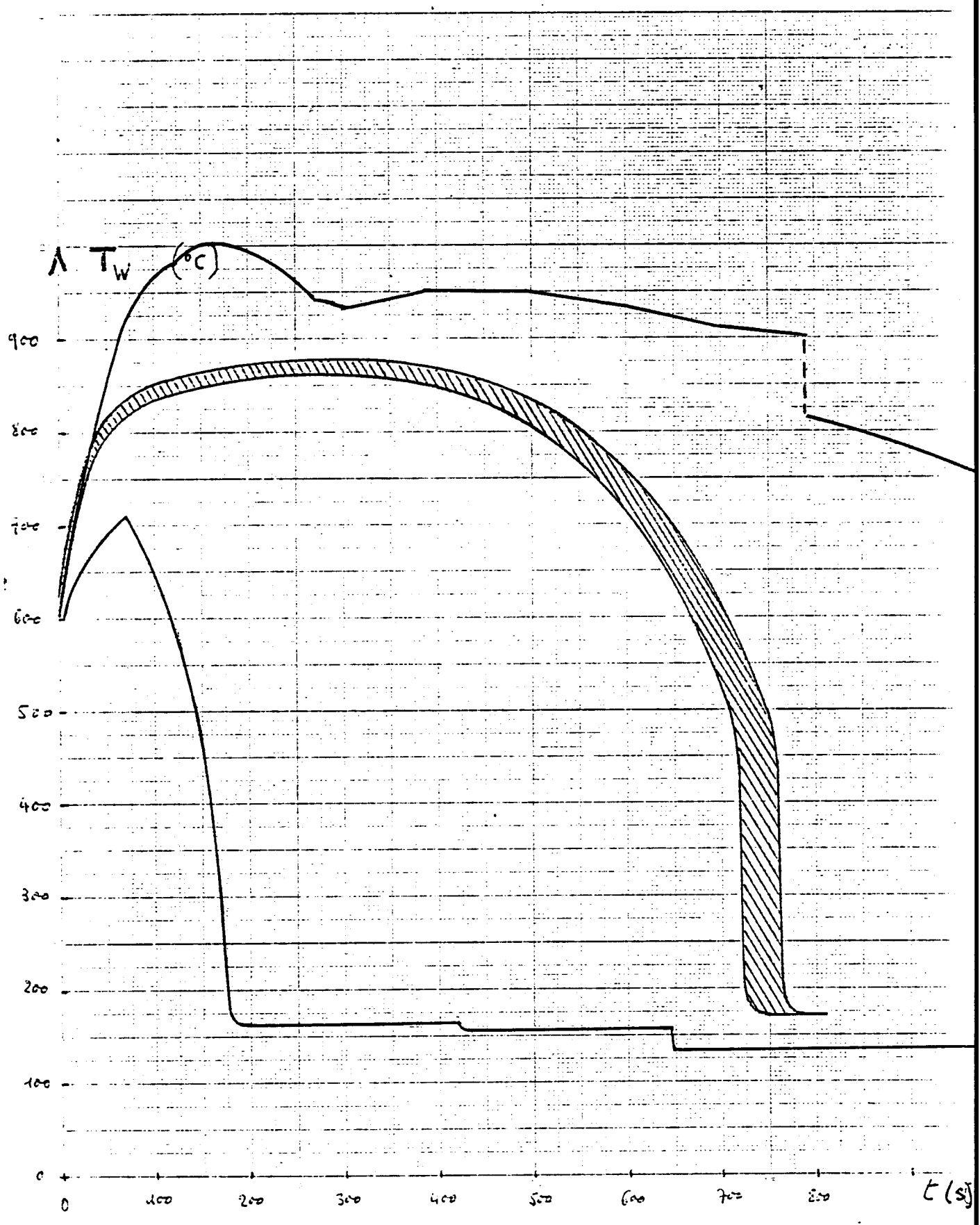
2 - Envelope of wall temperature predictions at 0.98 m elevation



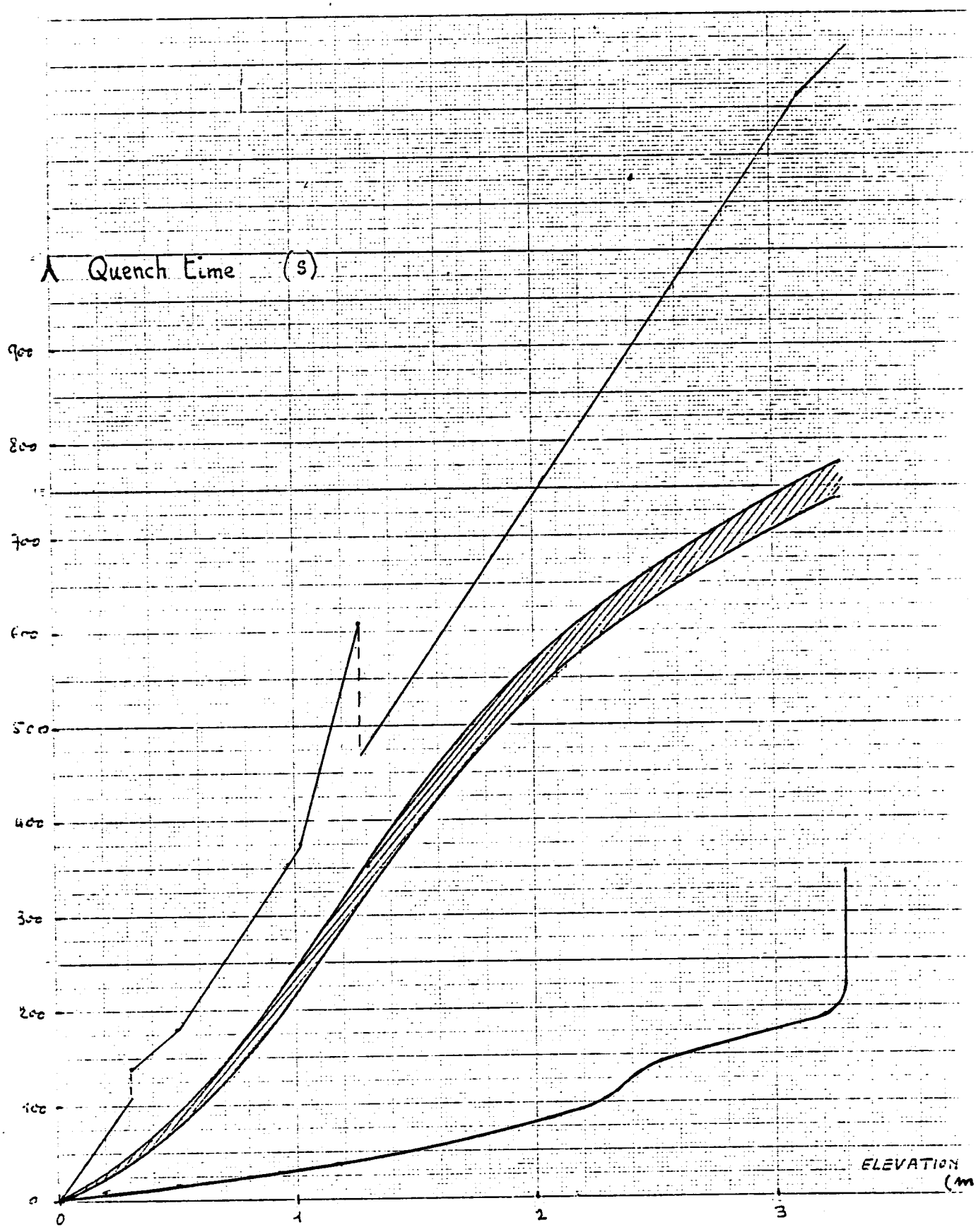
3 - Envelope of wall temperature predictions at 1.3 m elevation



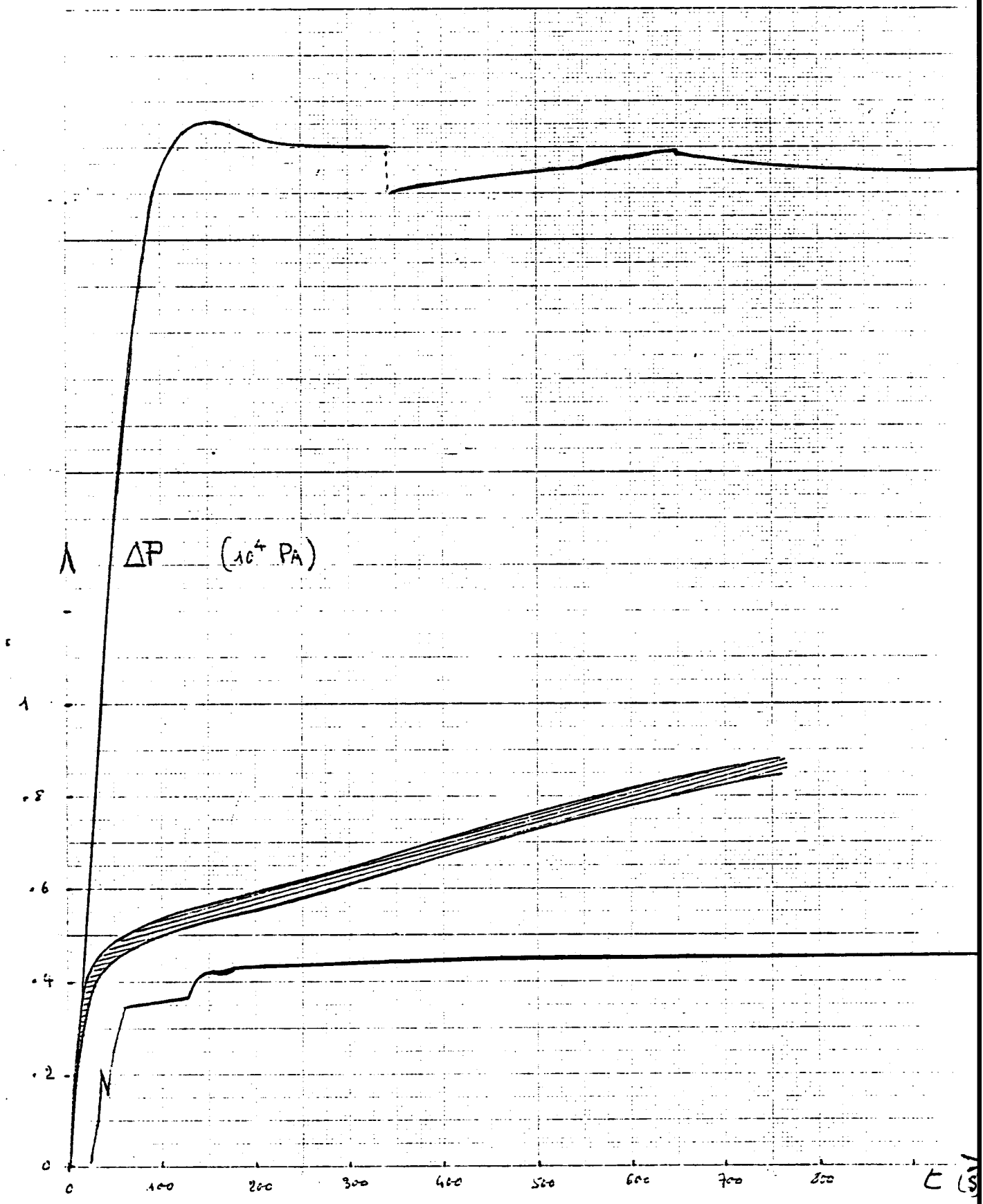
4 - Envelope of wall temperature predictions at 2.03 m elevation



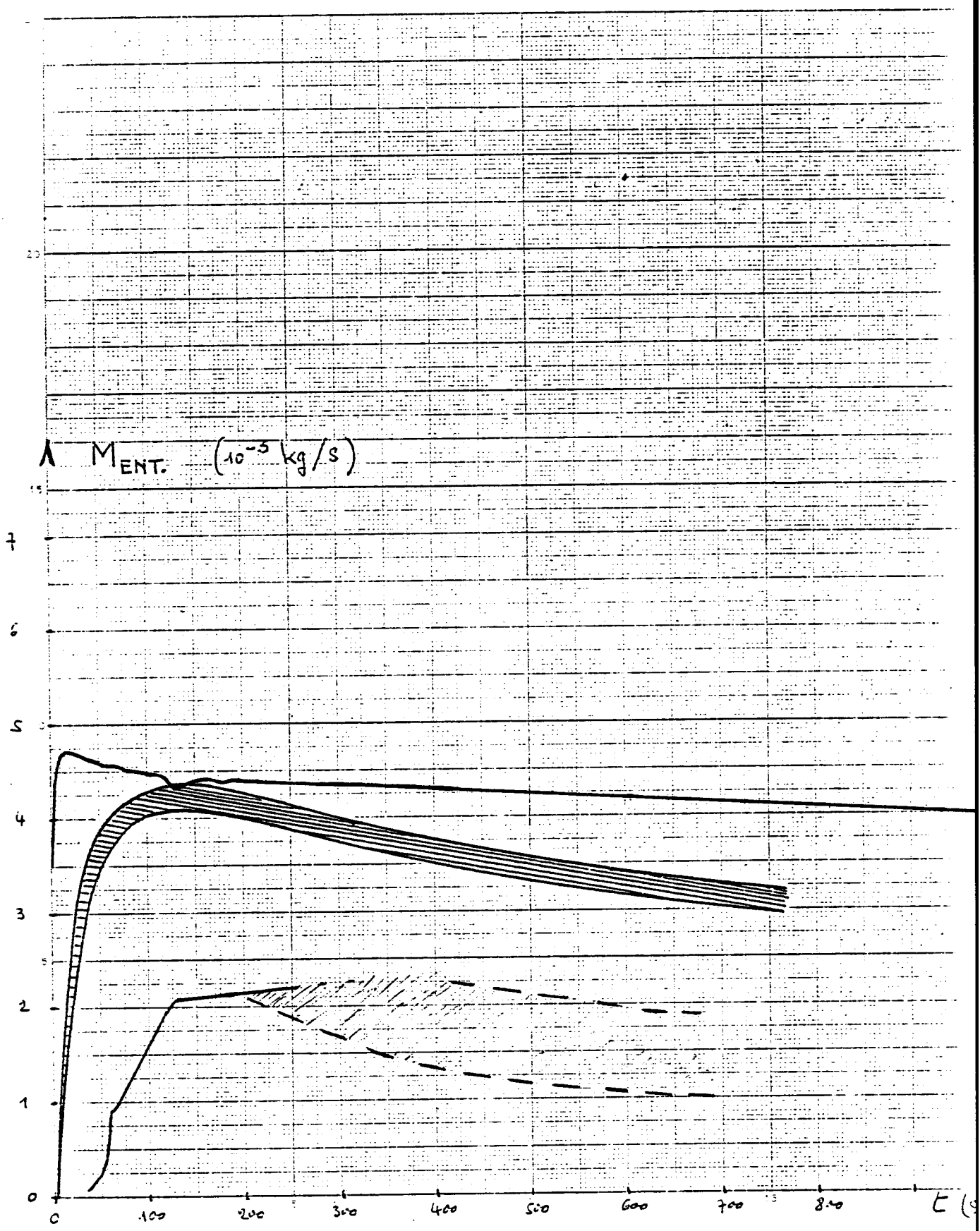
5 - Envelope of wall temperature predictions at 2.99 m elevation



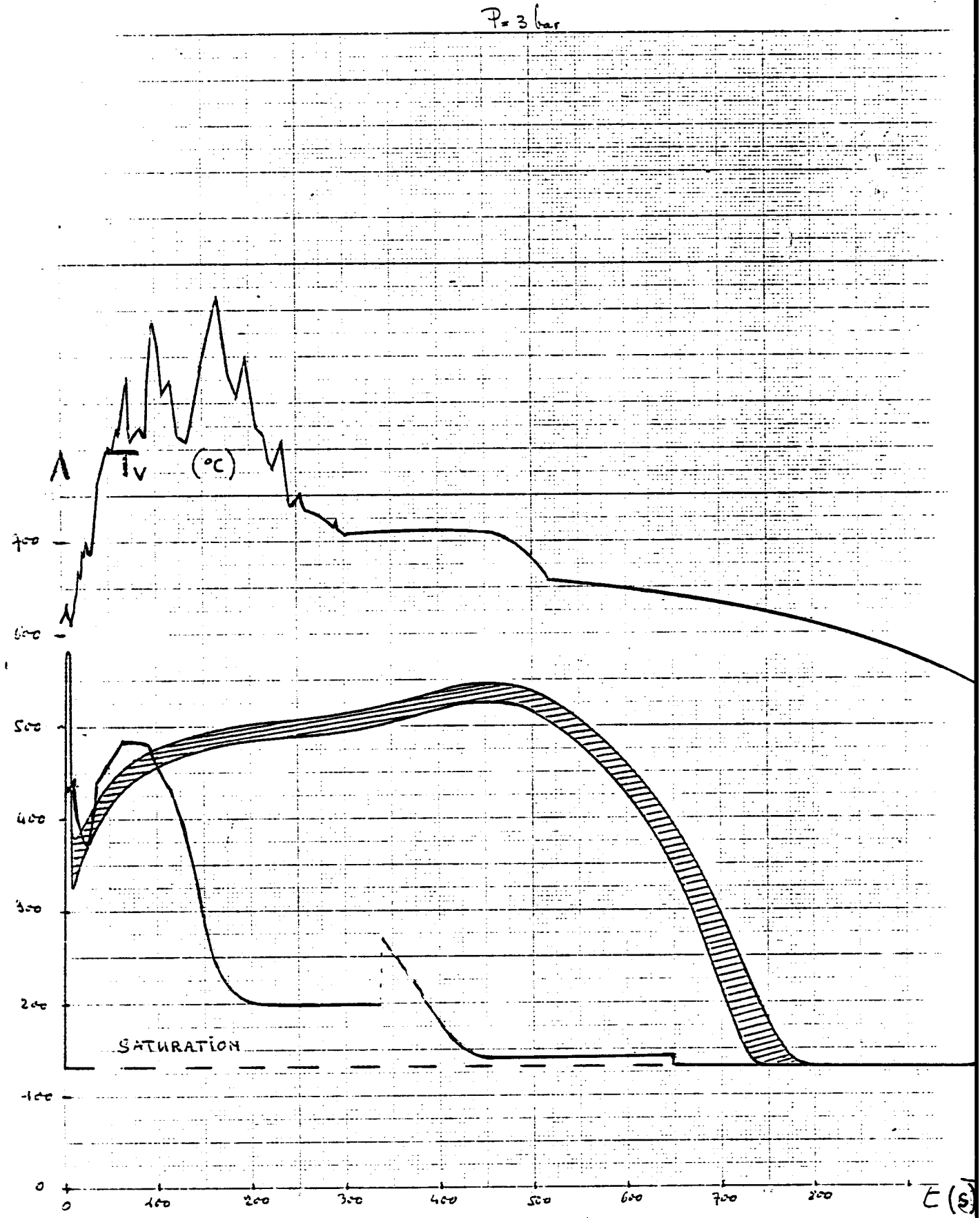
6 - Envelope of quench time predictions versus elevation



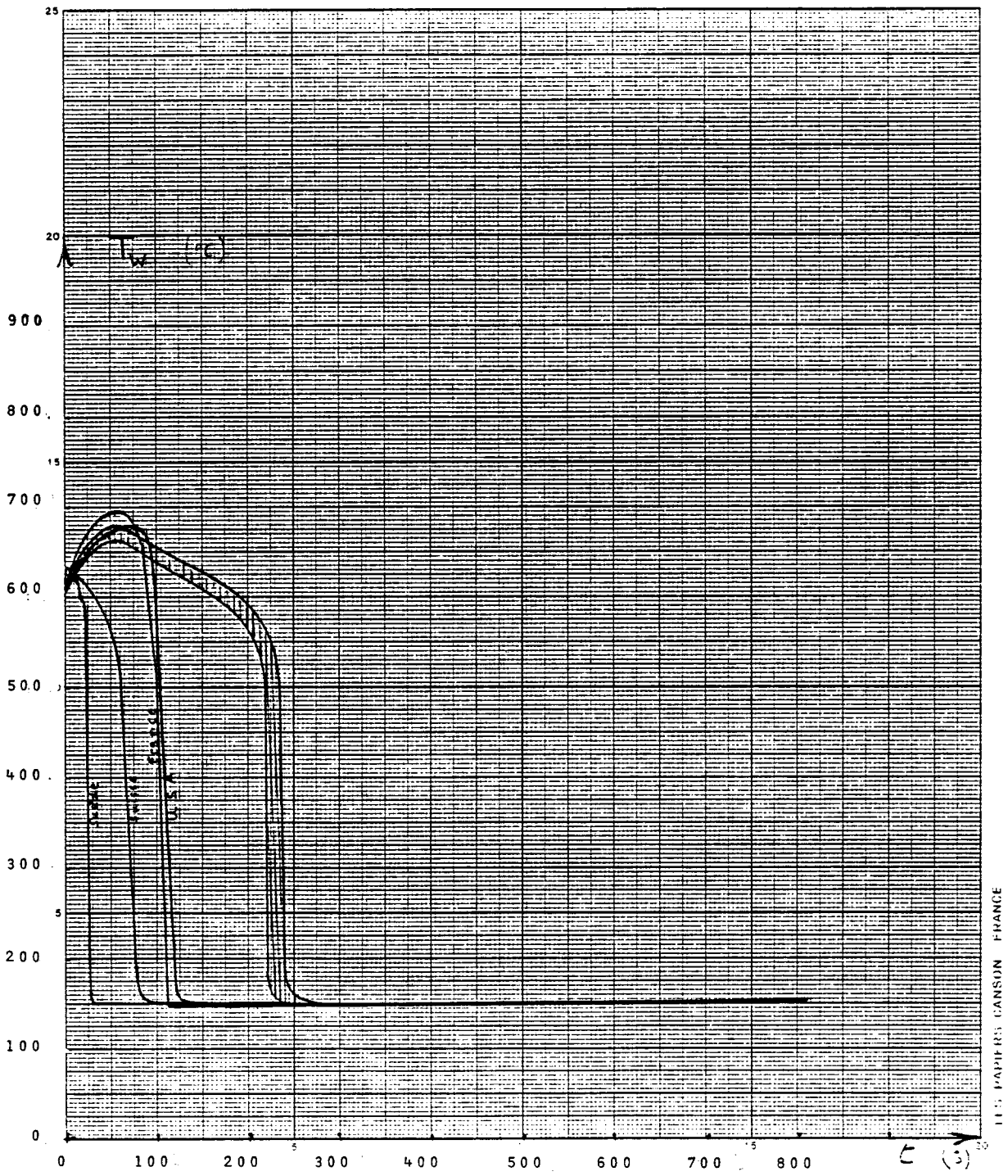
7 - Envelope of pressure drop predictions on the heated tube length.



8 - Envelope of mass flow rate of entrained water predictions at the outlet of the test section.

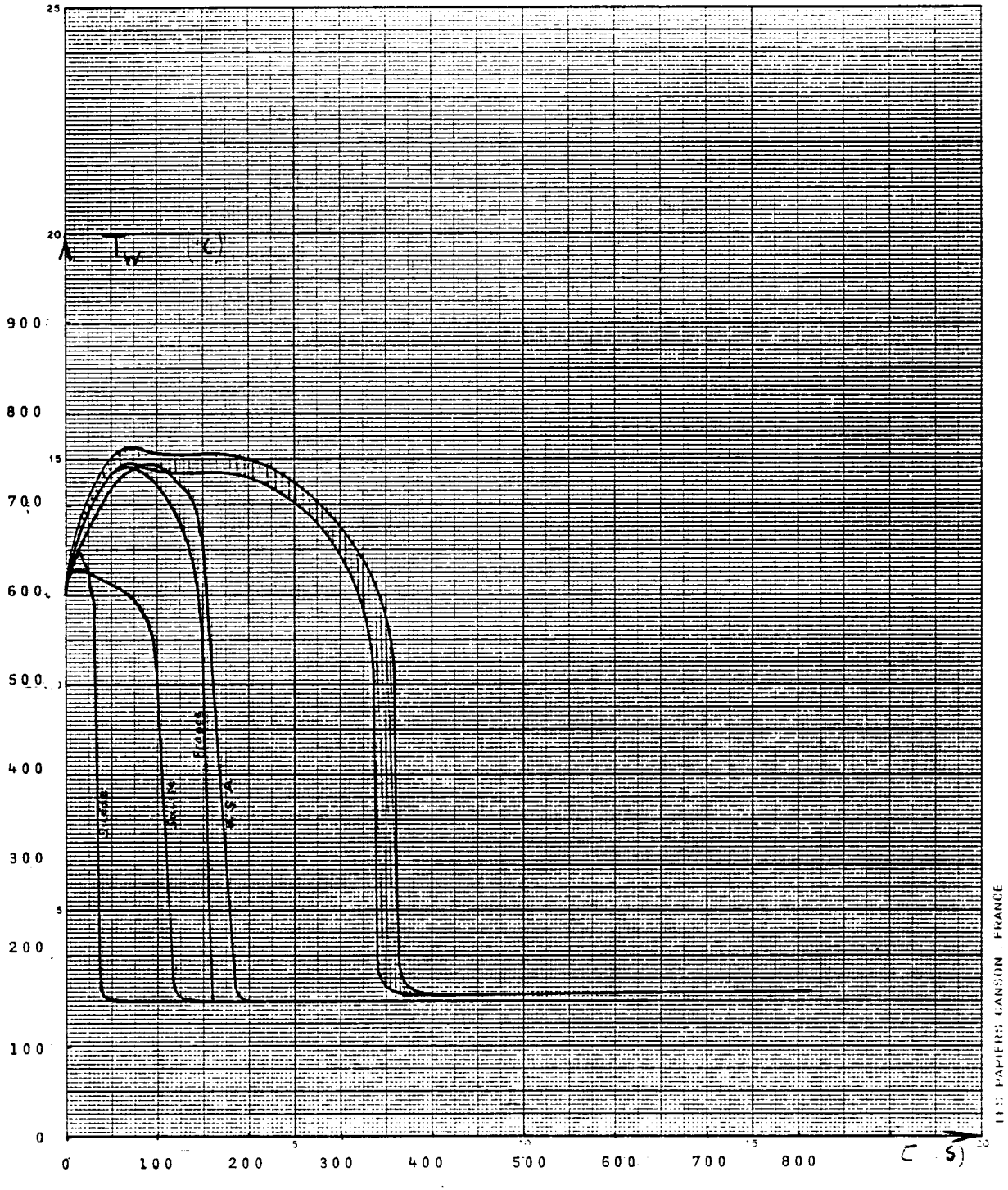


9 - Envelope of steam temperature predictions at the outlet of the test section.



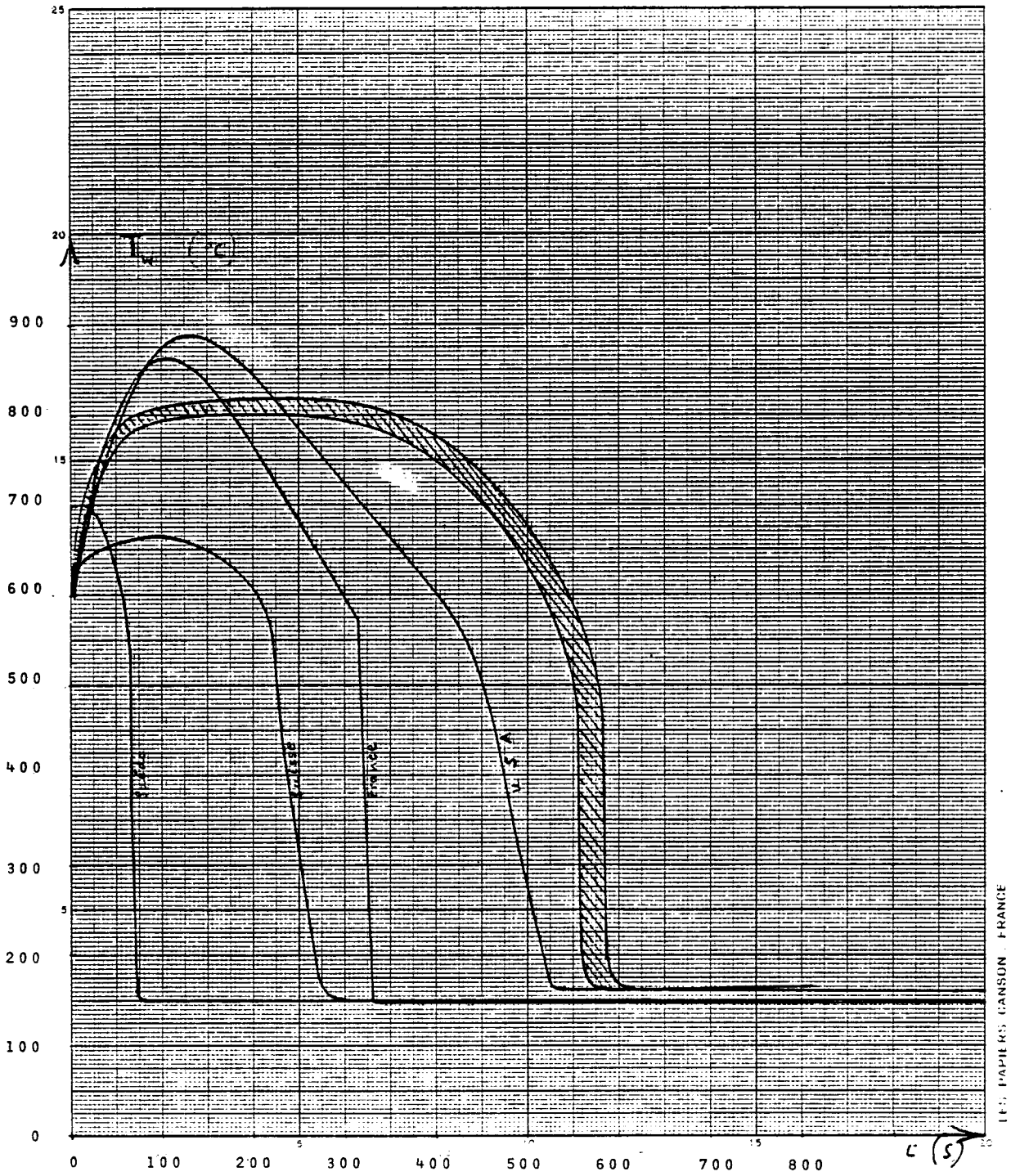
10 - Comparison of wall temperature predictions at 0.98 m elevation.

RELAP 4 mod 6 code



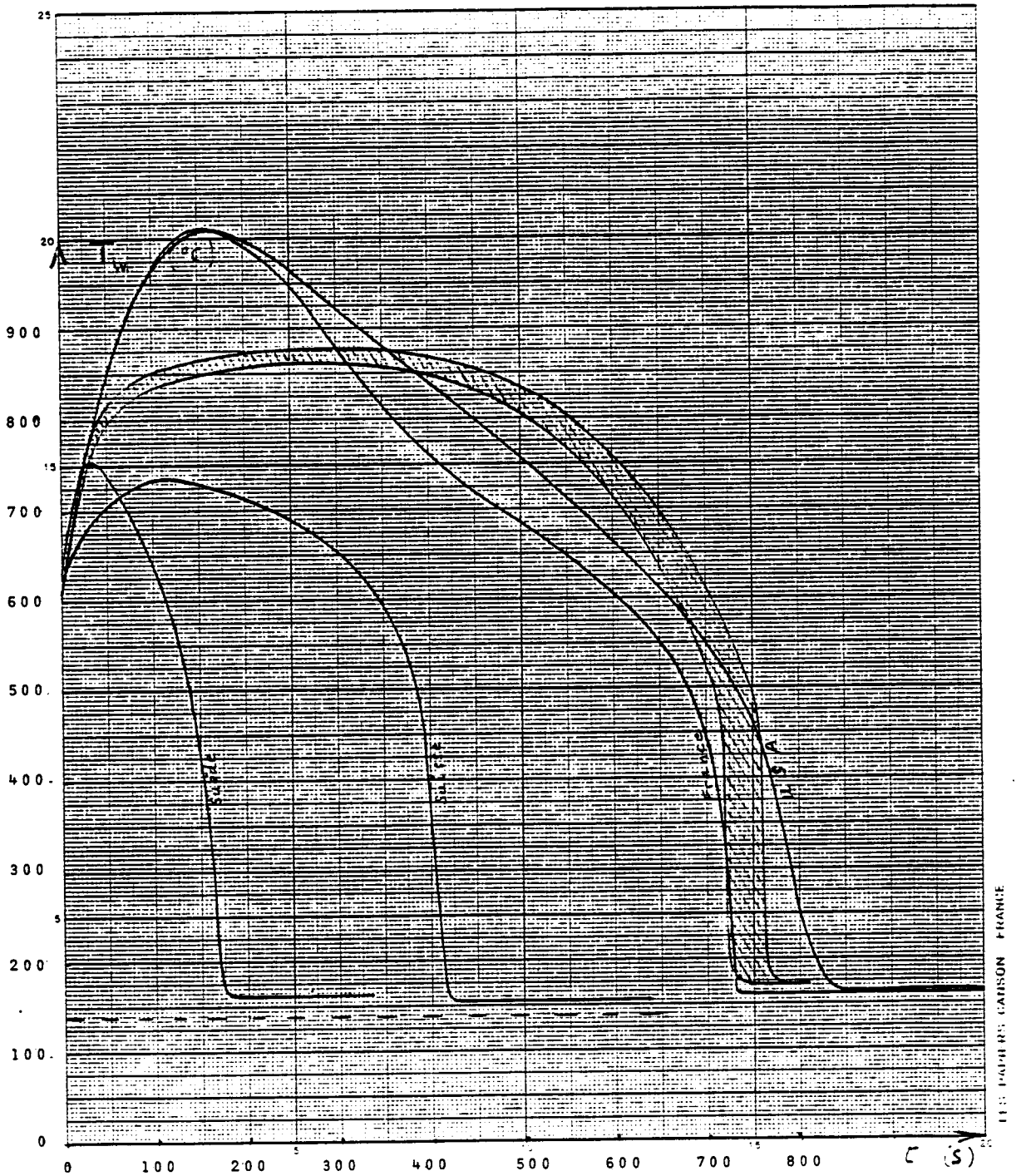
11 - Comparison of wall temperature predictions at 1.3 m elevation

RELAP 4 mod 6 code



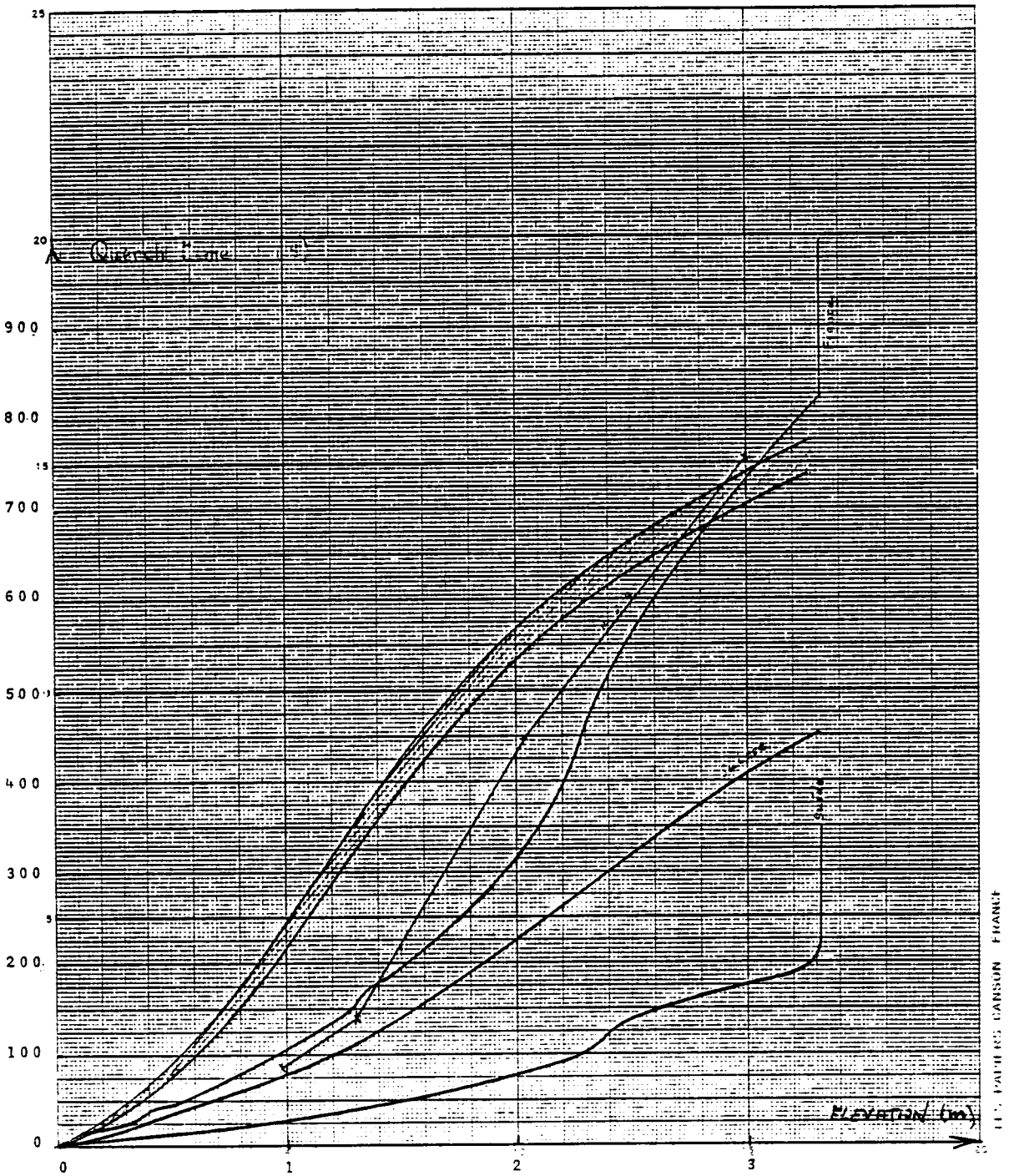
12 - Comparison of wall temperature predictions at 2.03 m elevation.

RELAP 4 mod 6 code



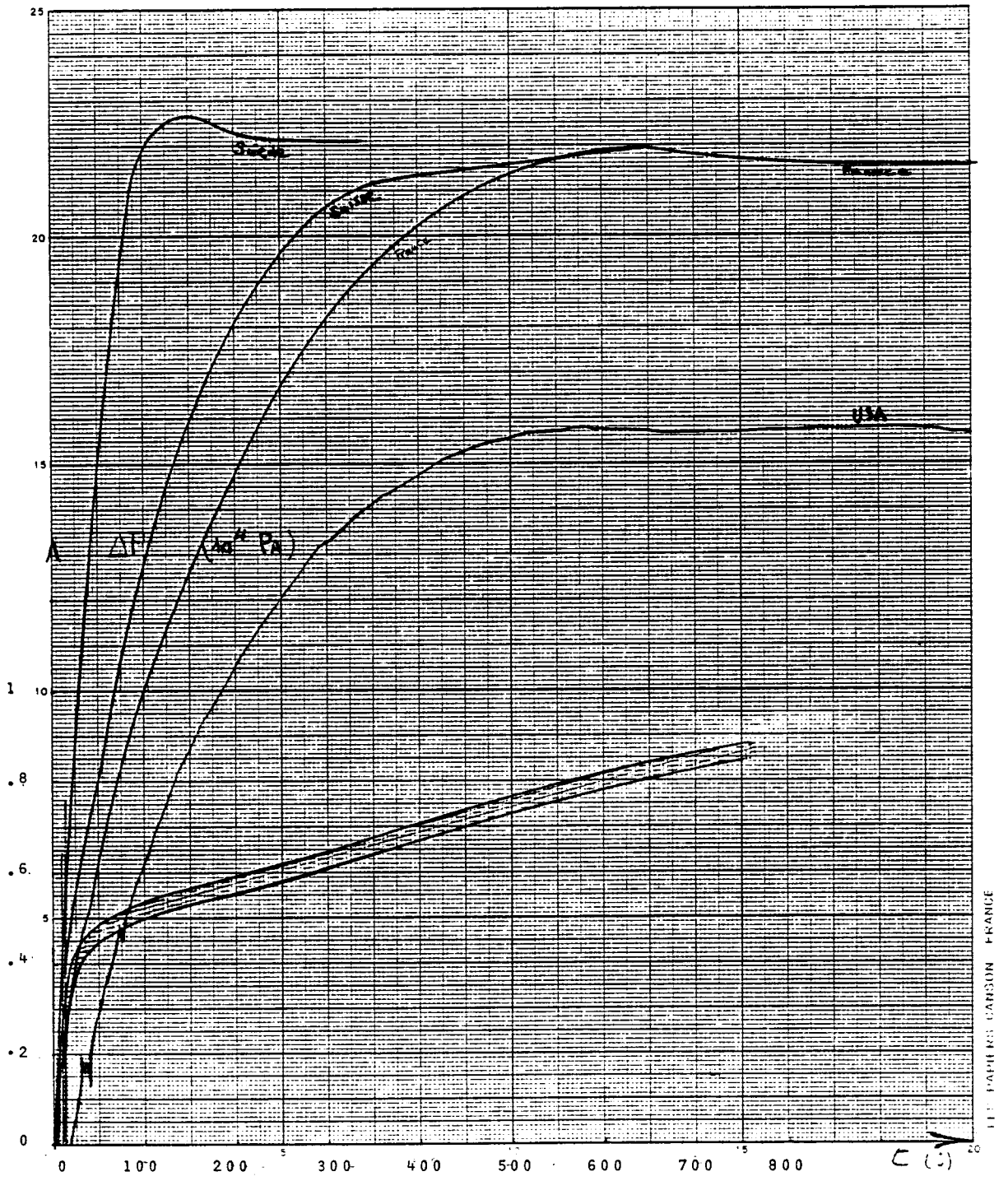
13 - Comparison of wall temperature predictions at 2.99 m elevation.

RELAP 4 mod 6 code



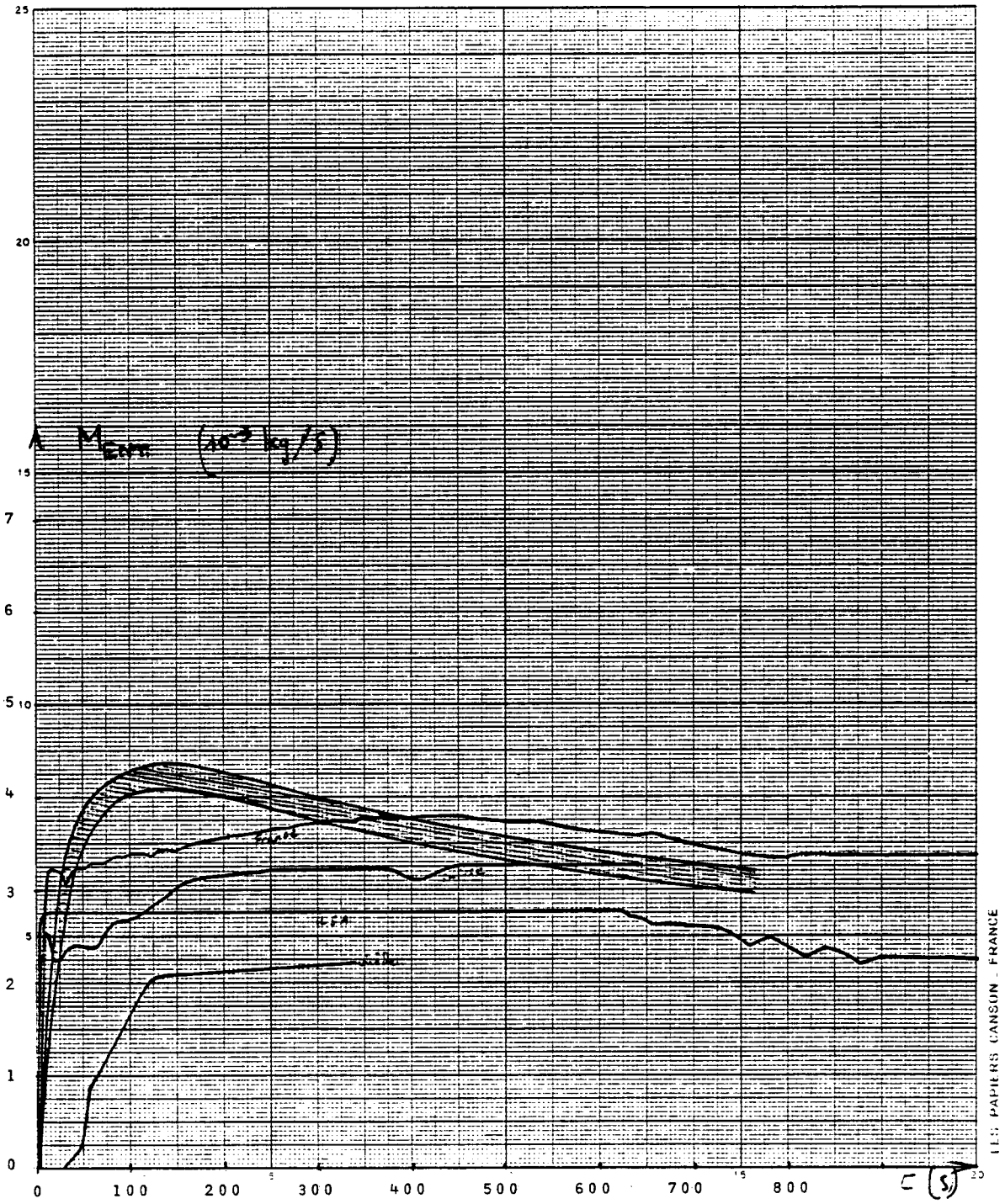
14 - Comparison of quench time predictions versus elevation.

RELAP 4 mod 6 code



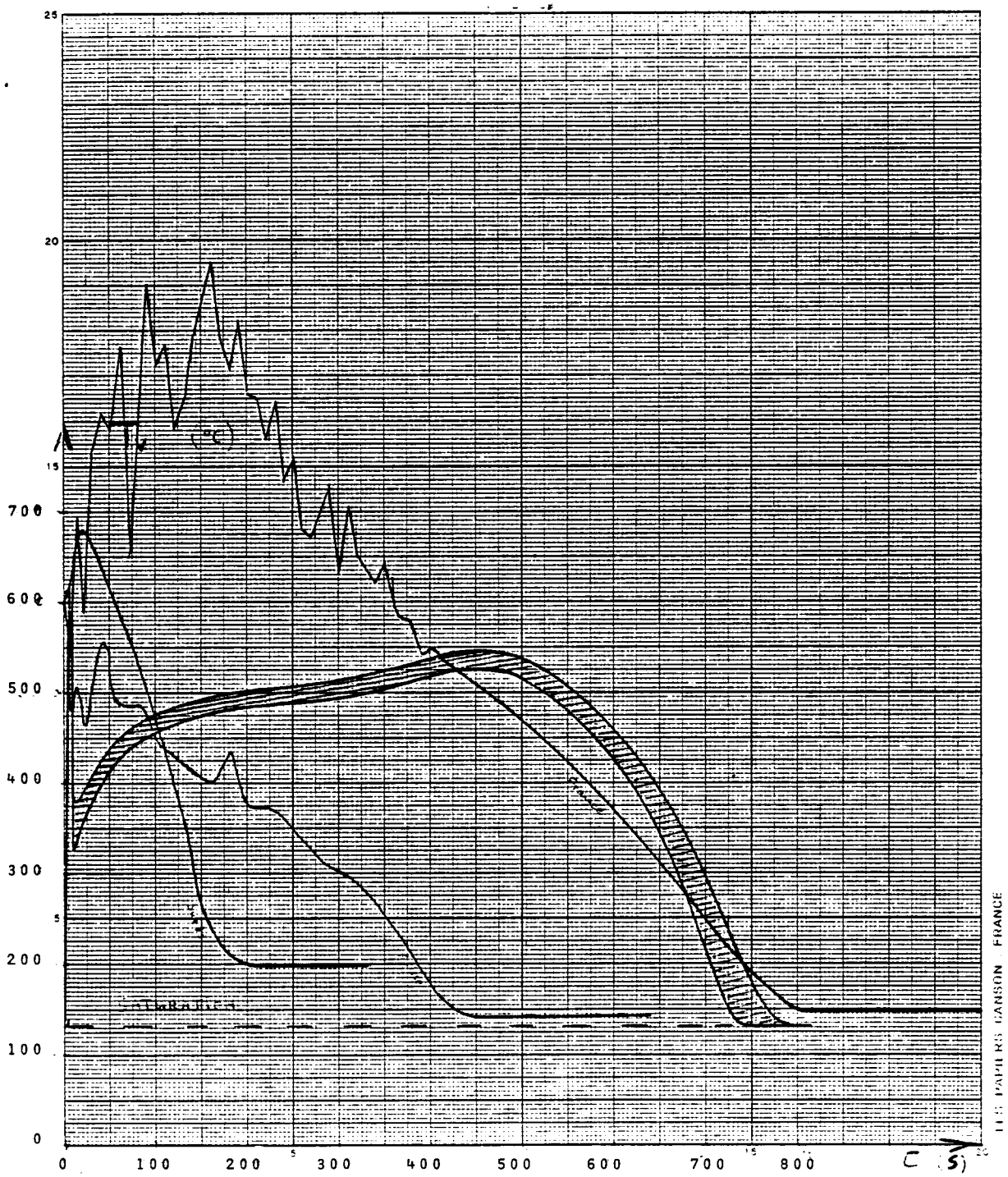
15 - Comparison of pressure drop predictions on the heated tube length.

RELAP 4 mod 6 code



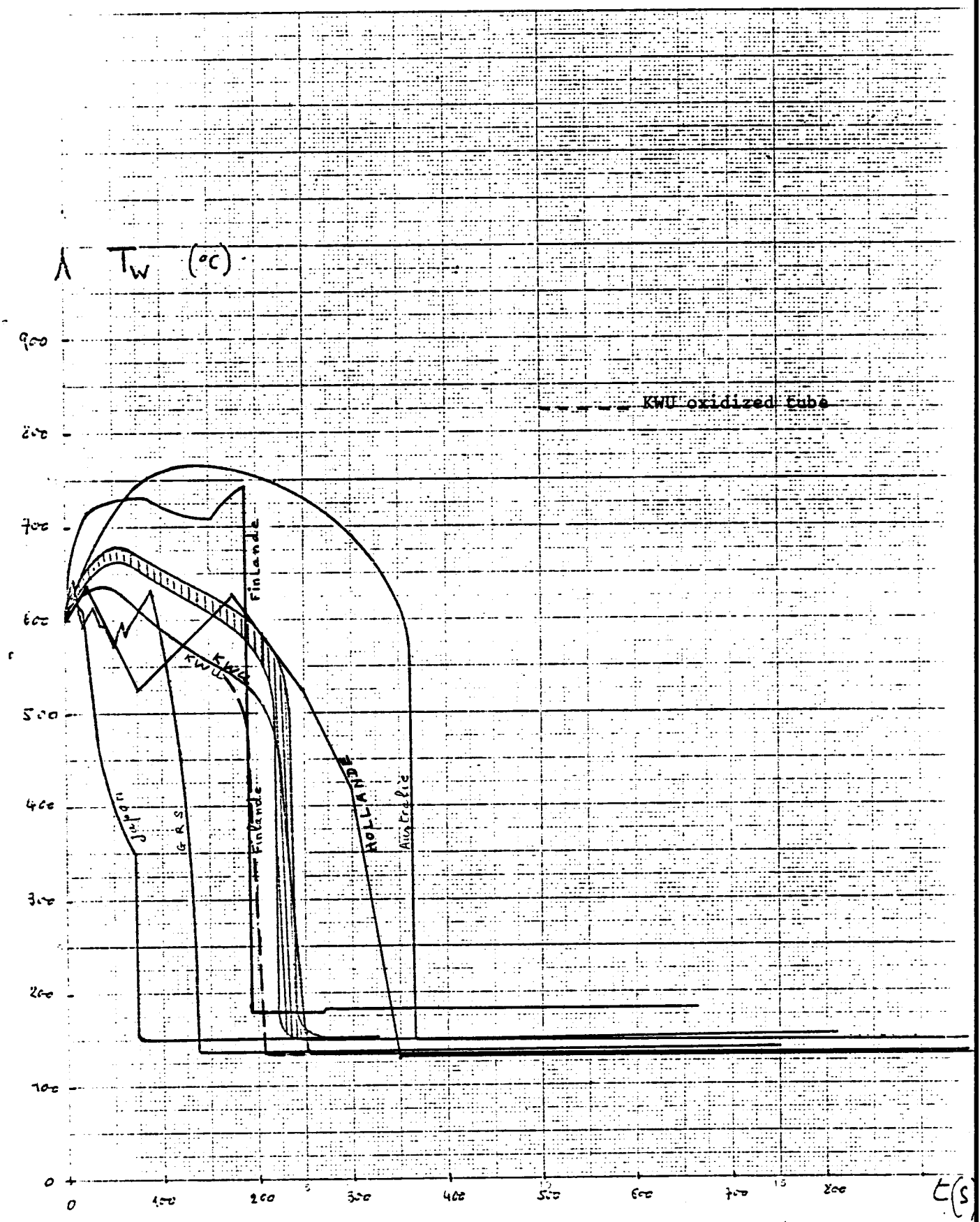
16 - Comparison of mass flow rate of entrained water predictions at the outlet of the test section.

RELAP 4 mod 6 code

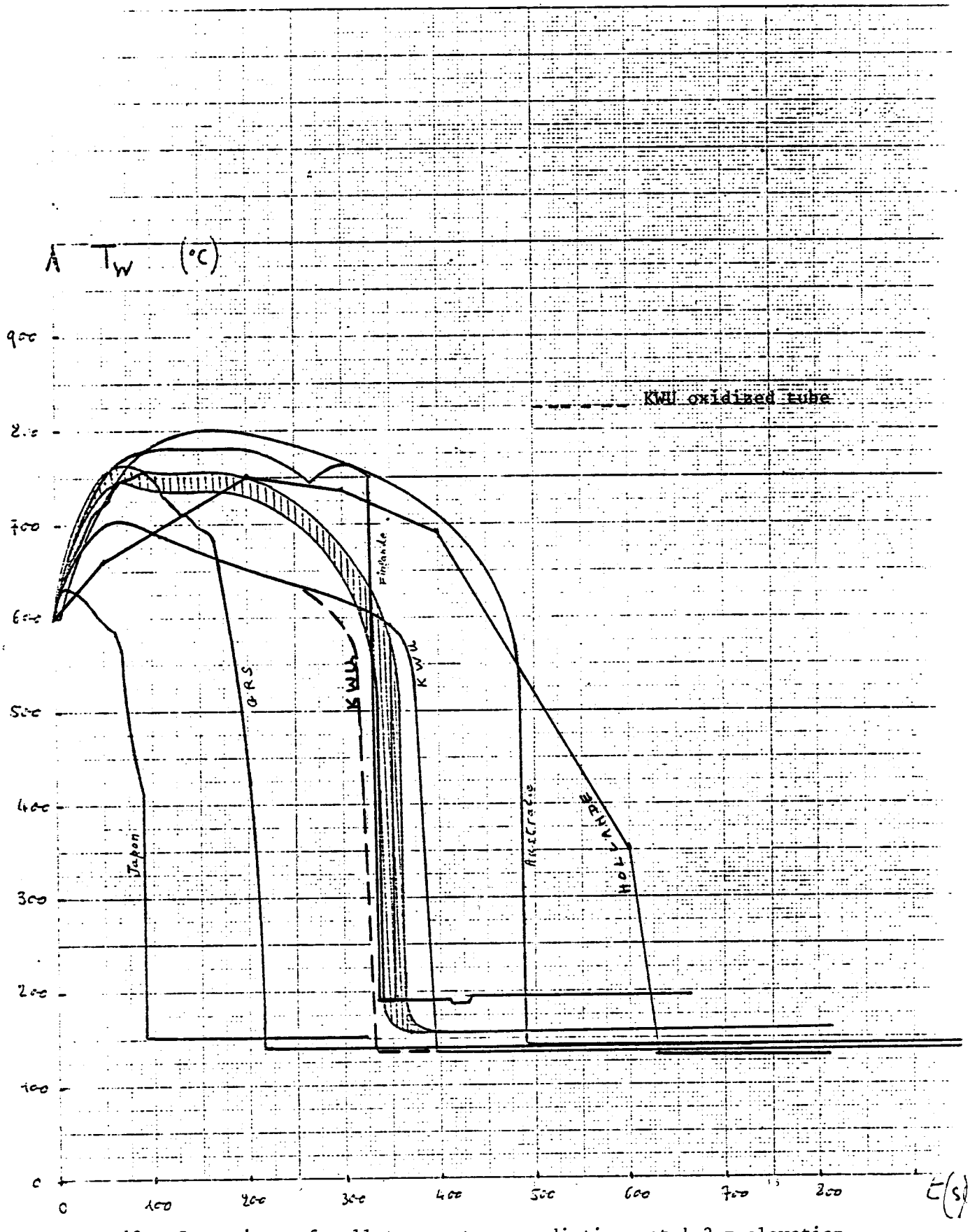


17 - Comparison of steam temperature predictions at the outlet of the test section.

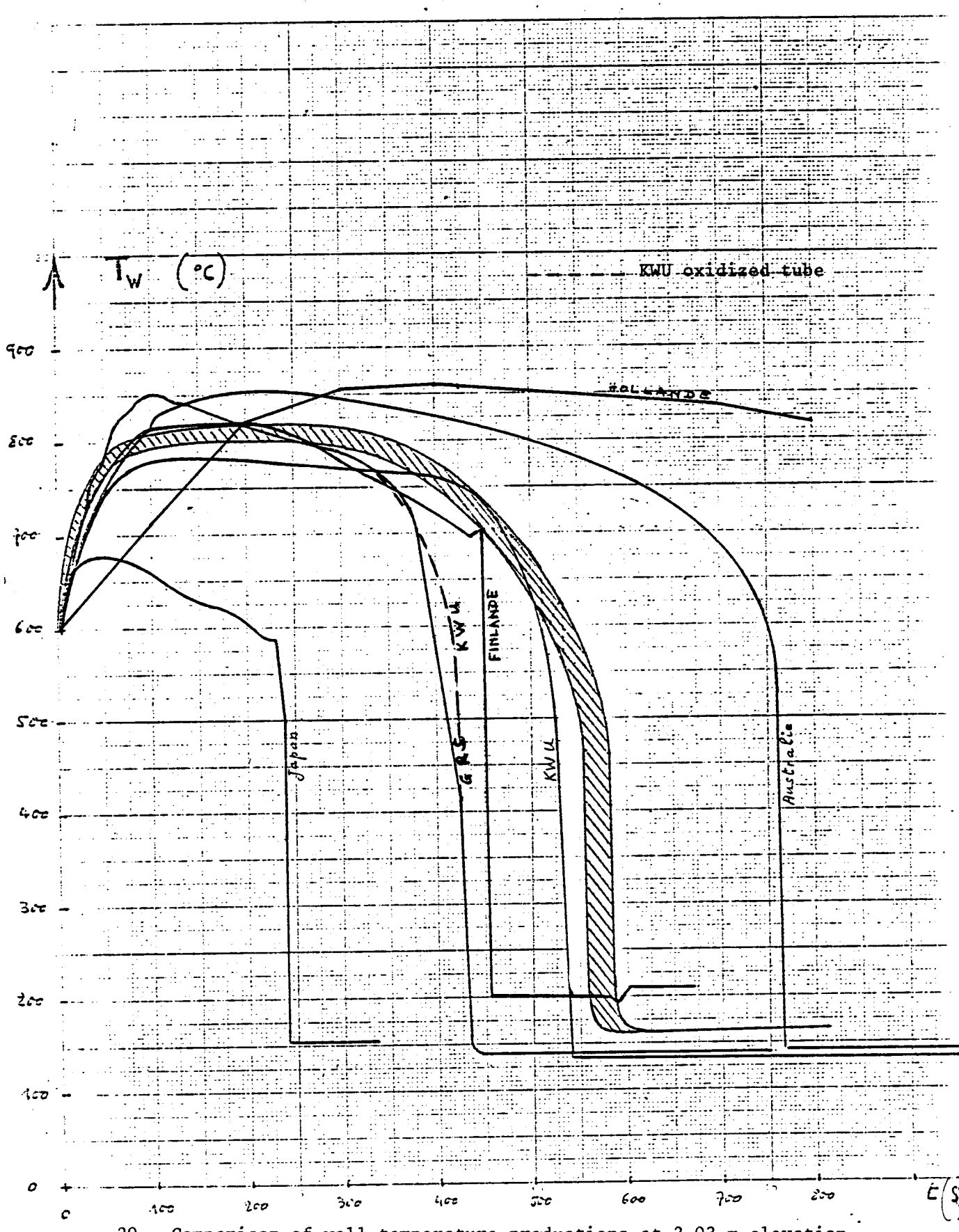
RELAP 4 mod 6 code



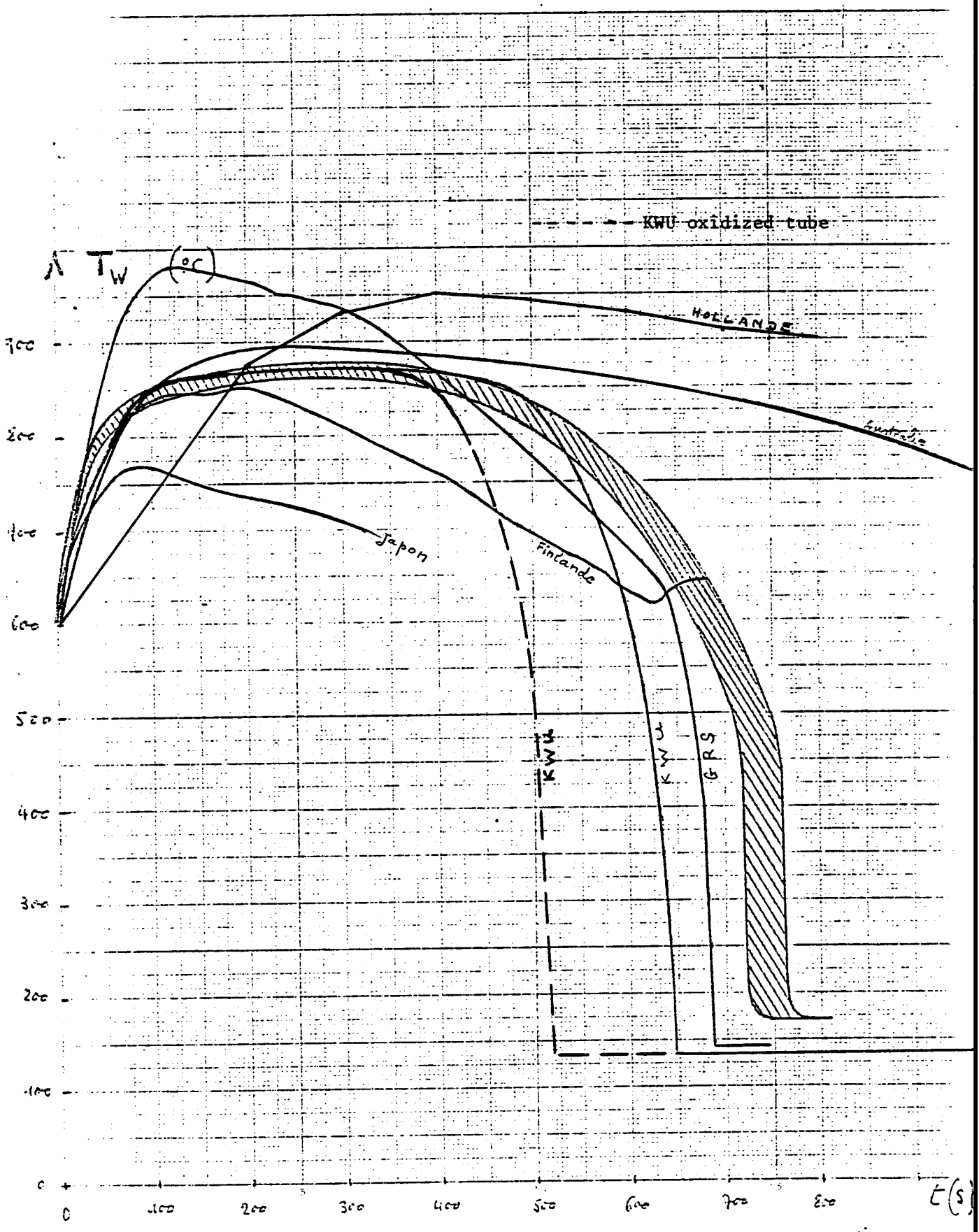
18 - Comparison of wall temperature predictions at 0.98 m elevation with other codes than RELAP 4 mod 6.



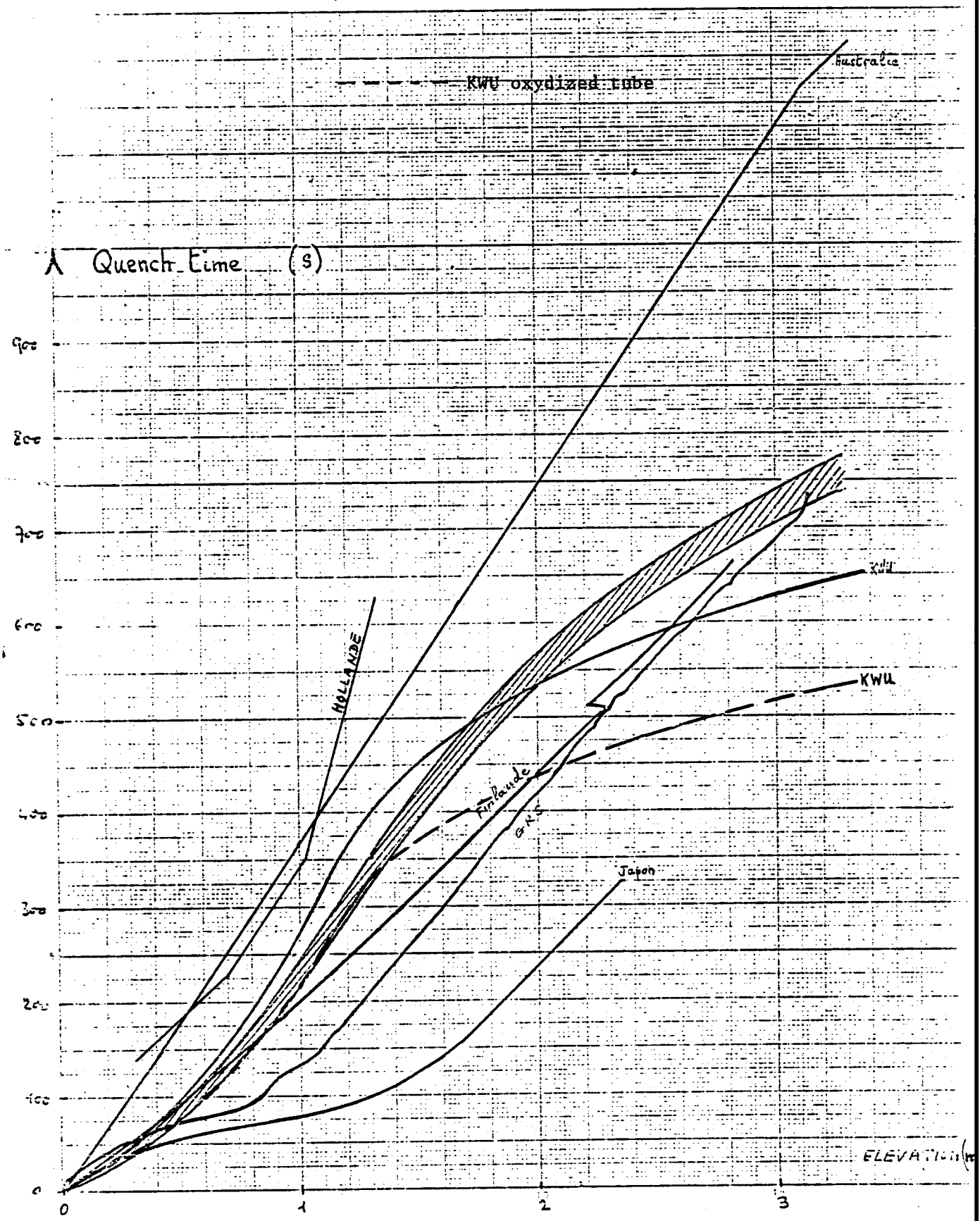
19 - Comparison of wall temperature predictions at 1.3 m elevation with other codes than RELAP 4 mod 6.



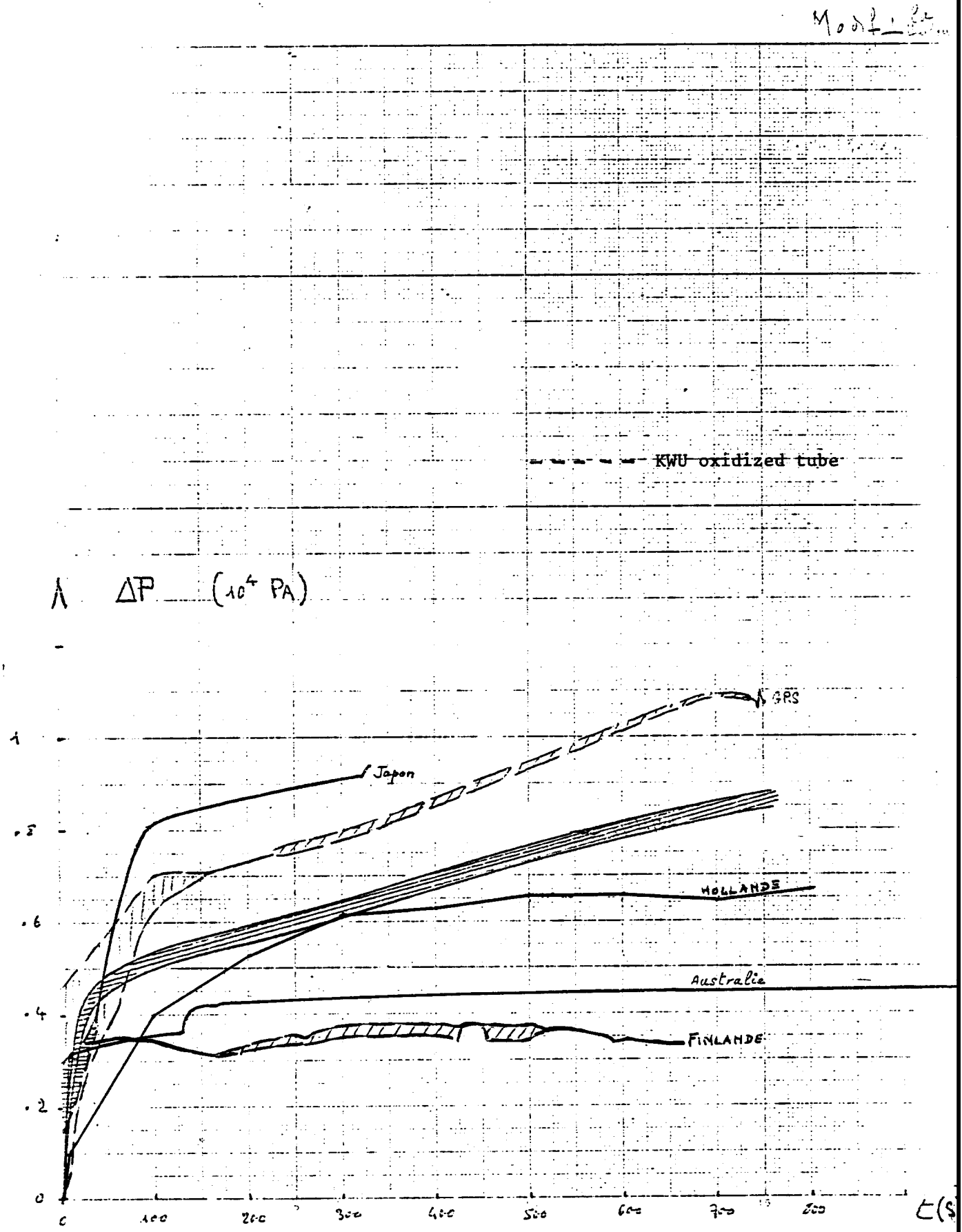
20 - Comparison of wall temperature preductions at 2.03 m elevation with other codes than RELAP 4 mod 6.



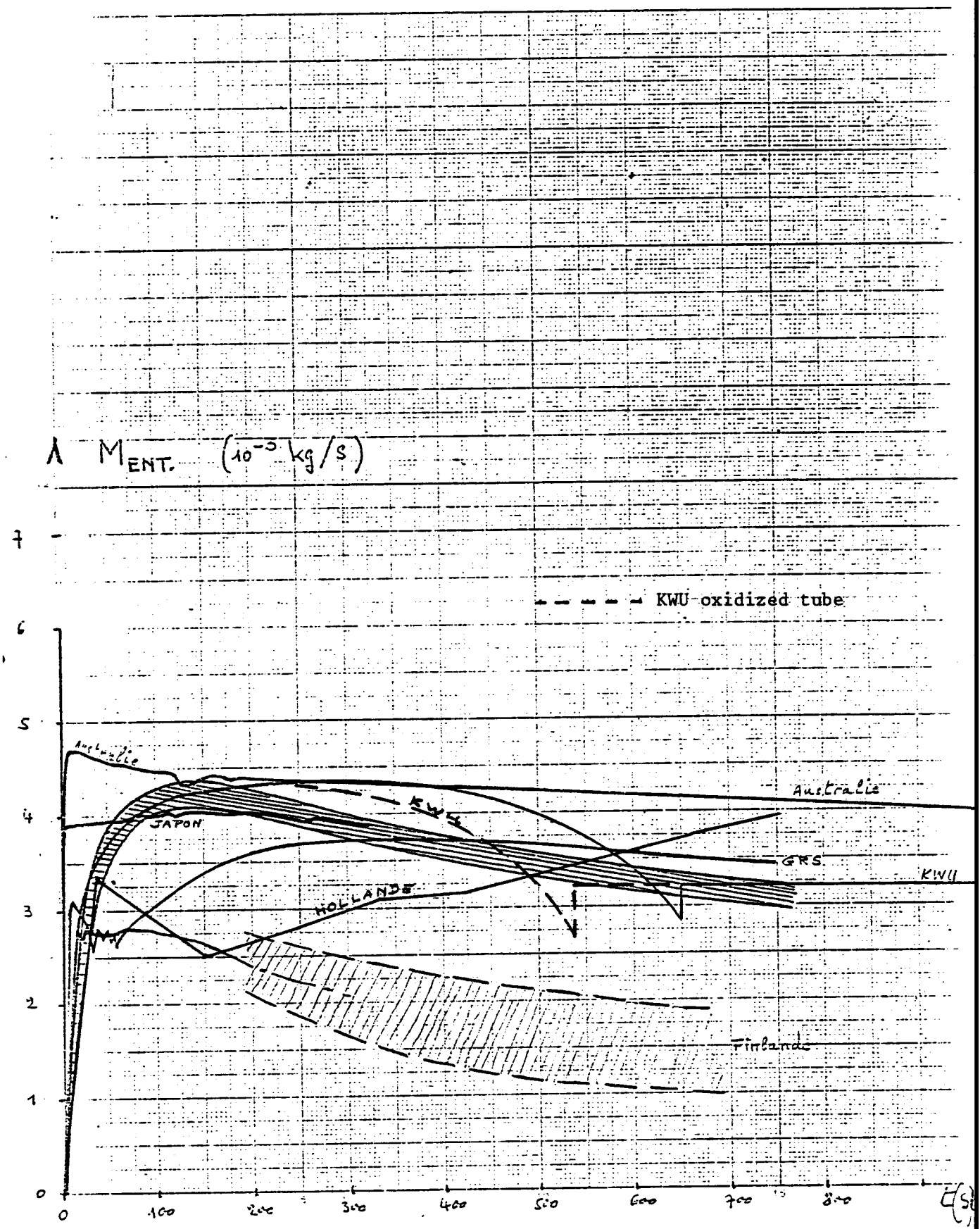
21 - Comparison of wall temperature predictions at 2.99 m elevation with other codes than RELAP 4 mod 6.



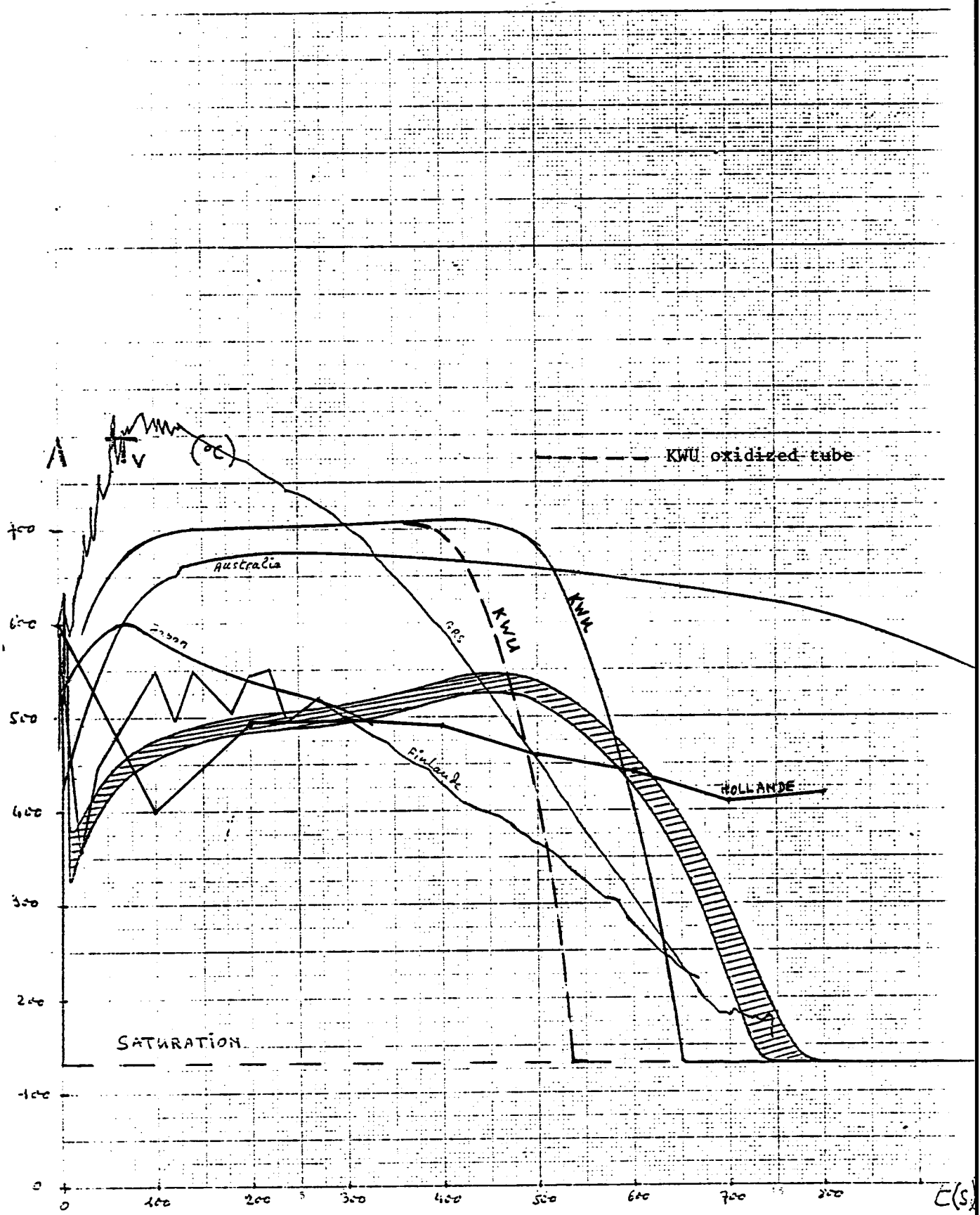
22 - Comparison of quench time predictions versus elevation with other codes than RELAP 4 mod 6.



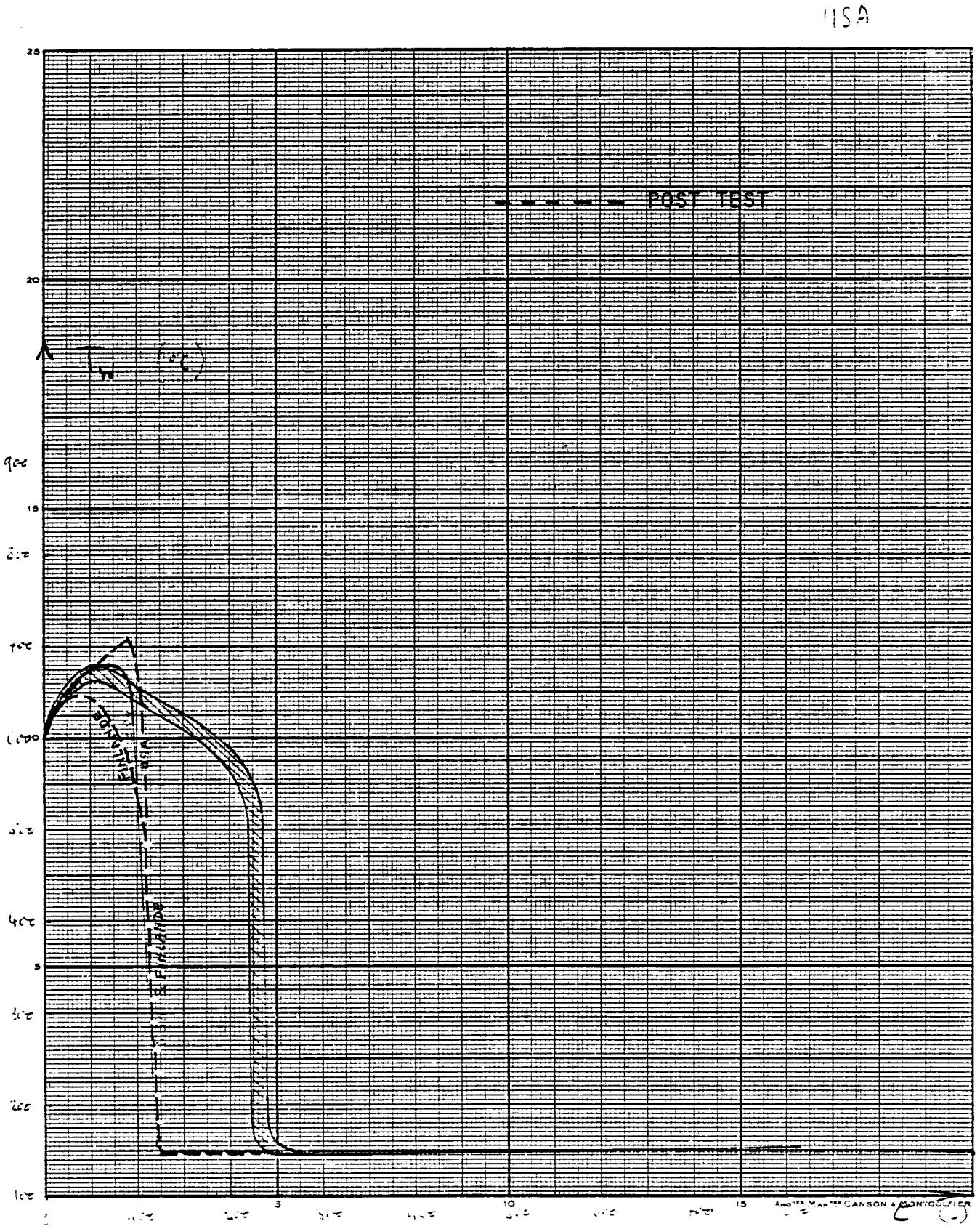
23 - Comparison of pressure drop predictions on the heated tube length with other codes than RELAP 4 mod 6.



24 - Comparison of mass flow rate of entrained water predictions at the outlet of the test section with other codes than RELAP 4 mod 6.

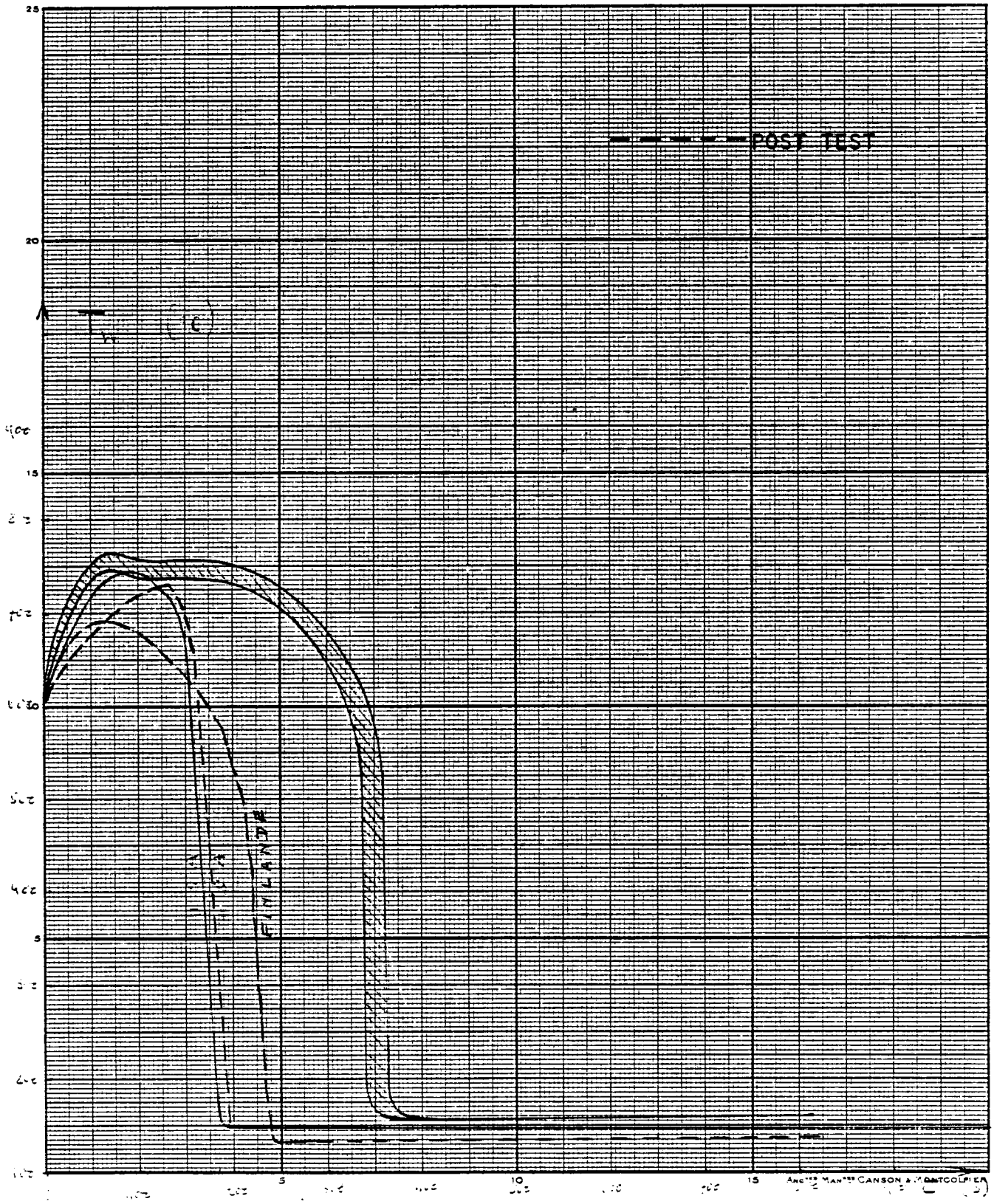


25 - Comparison of steam temperature predictions at the outlet of the test section with other codes than RELAP 4 mod 6.

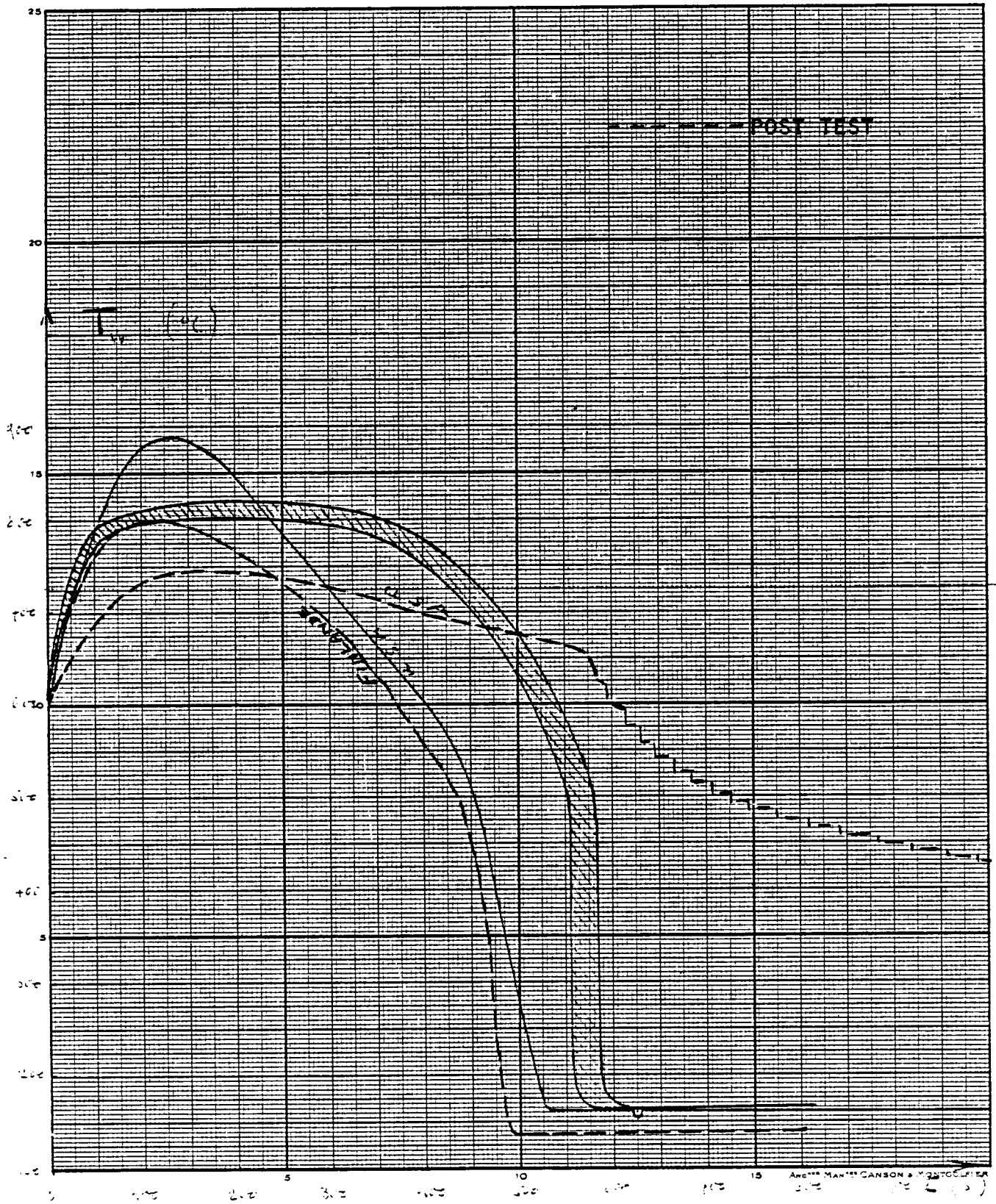


26 - Post test calculations with RELAP 4 mod 6
Wall temperature at 0.98 m elevation.

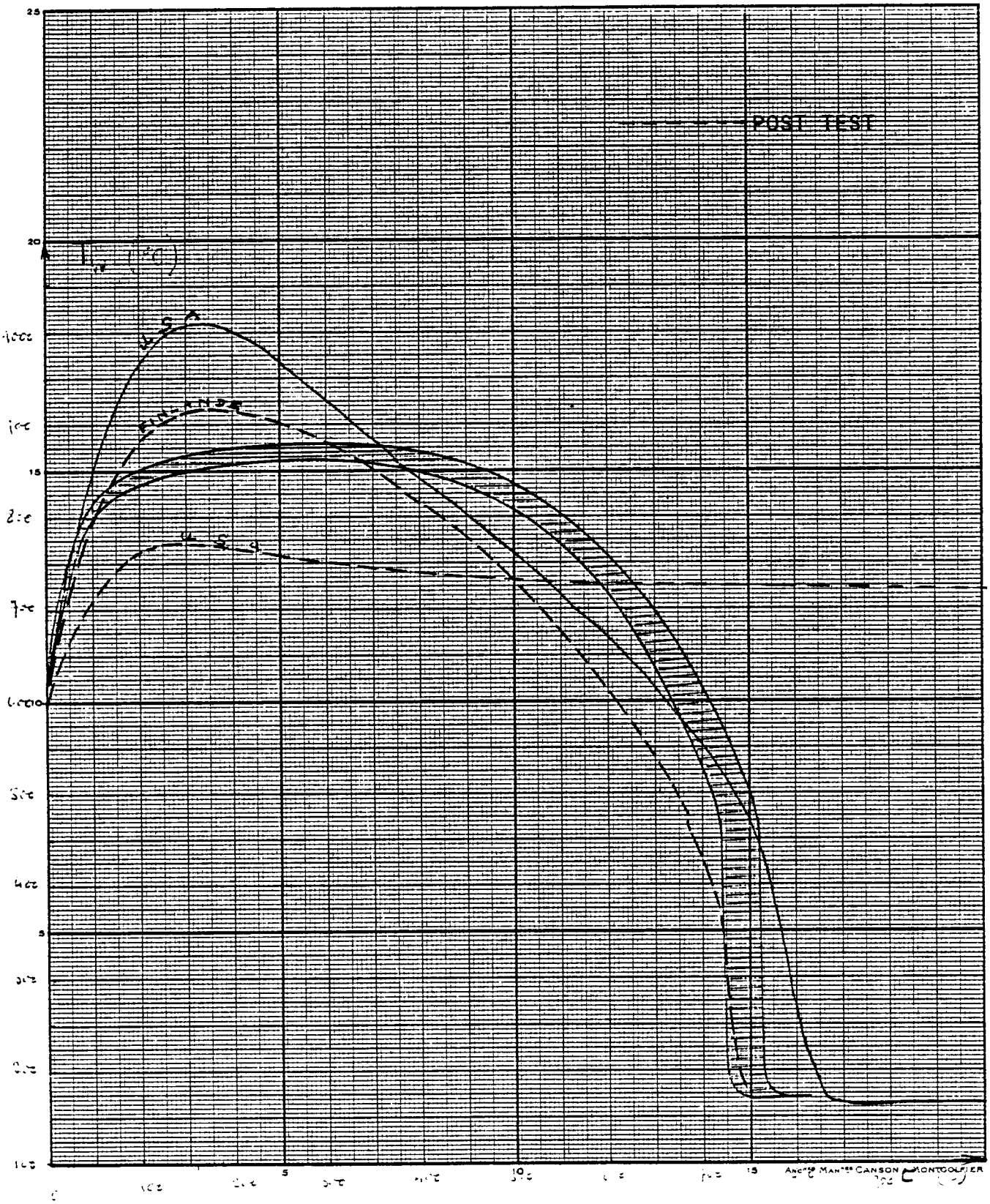
USA



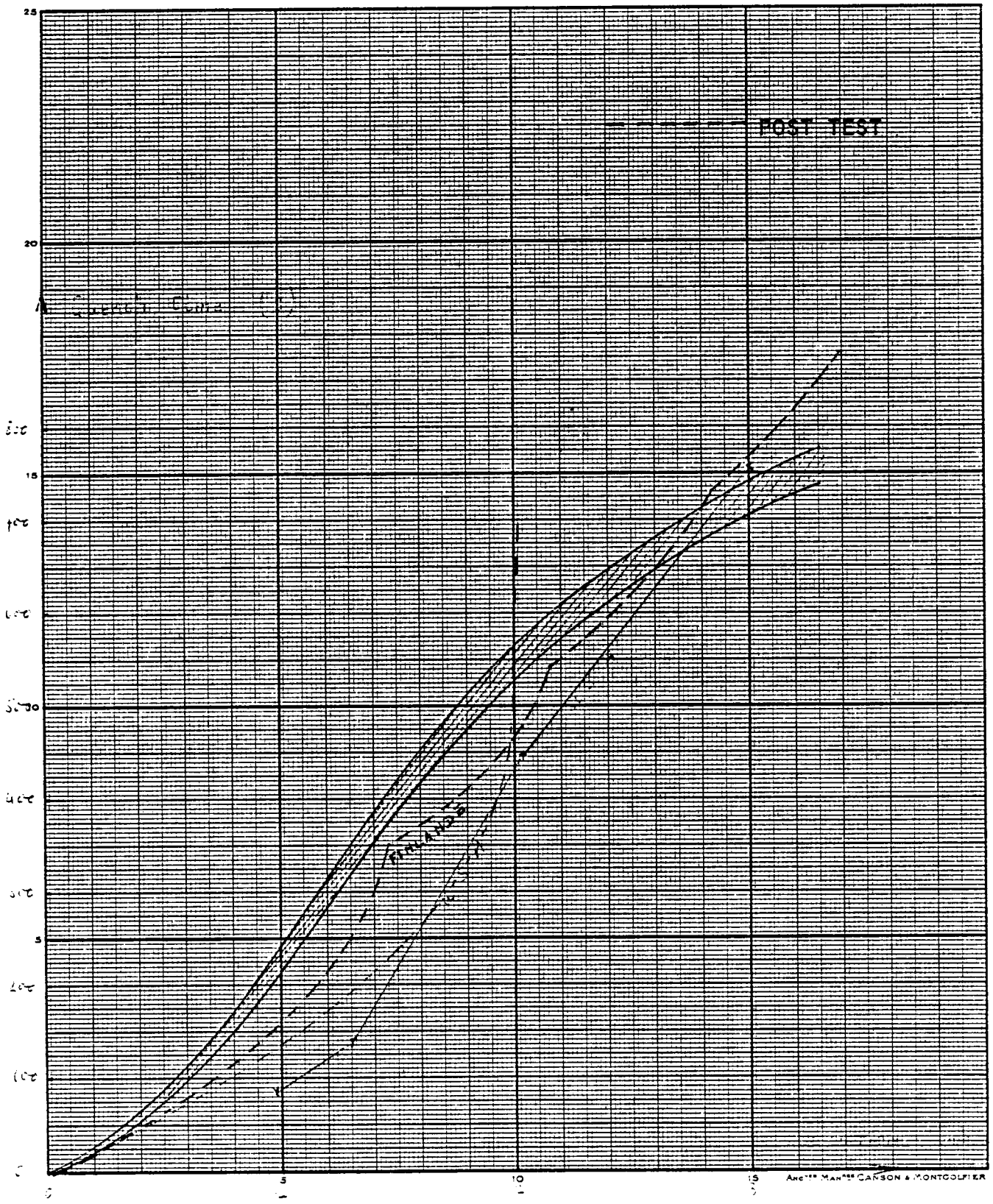
27 - Post test calculations with RELAP 4 mod 6
Wall temperature at 1.3 m elevation.



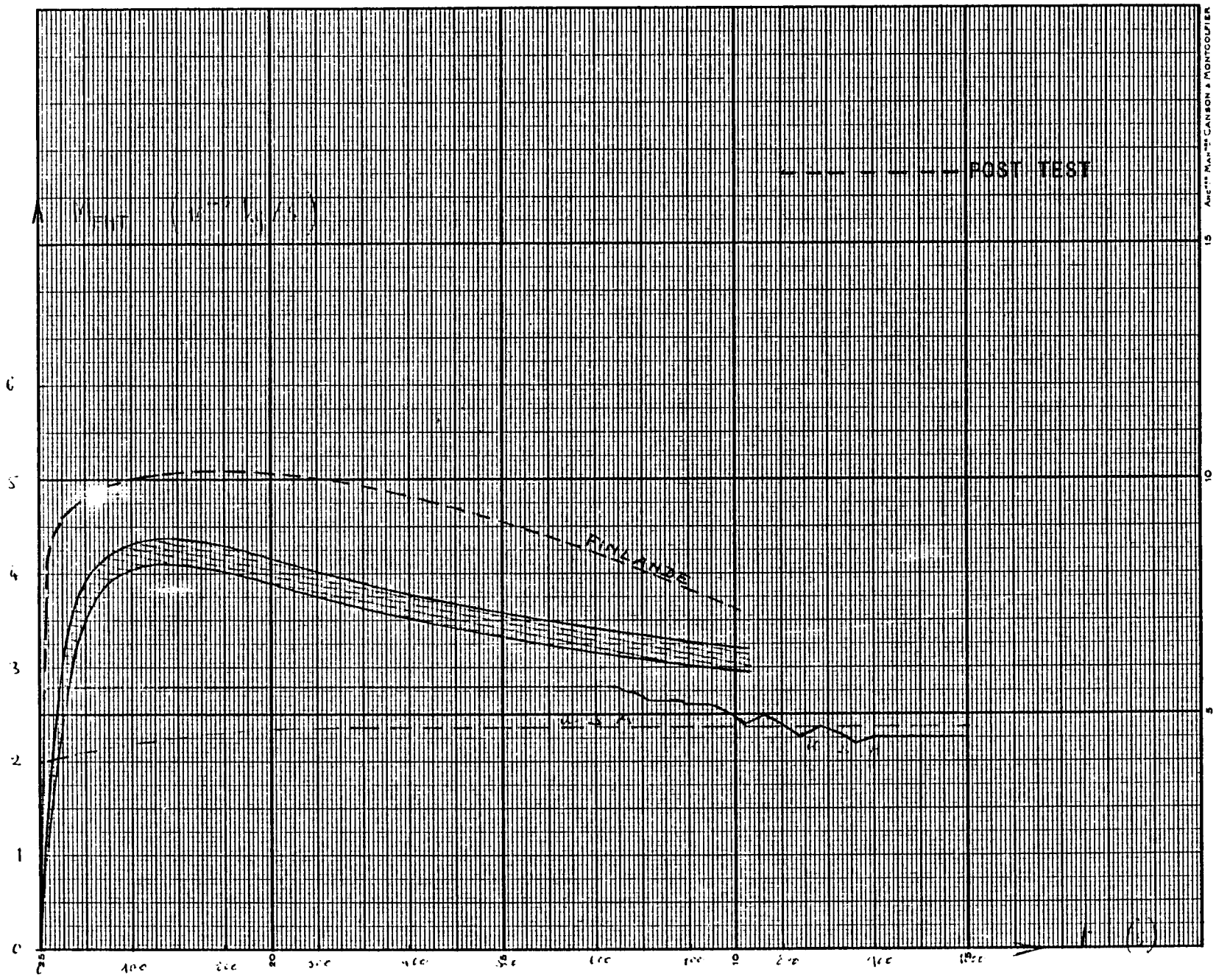
28 - Post test calculations with RELAP 4 mod 6
Wall temperature at 2.03 m elevation.



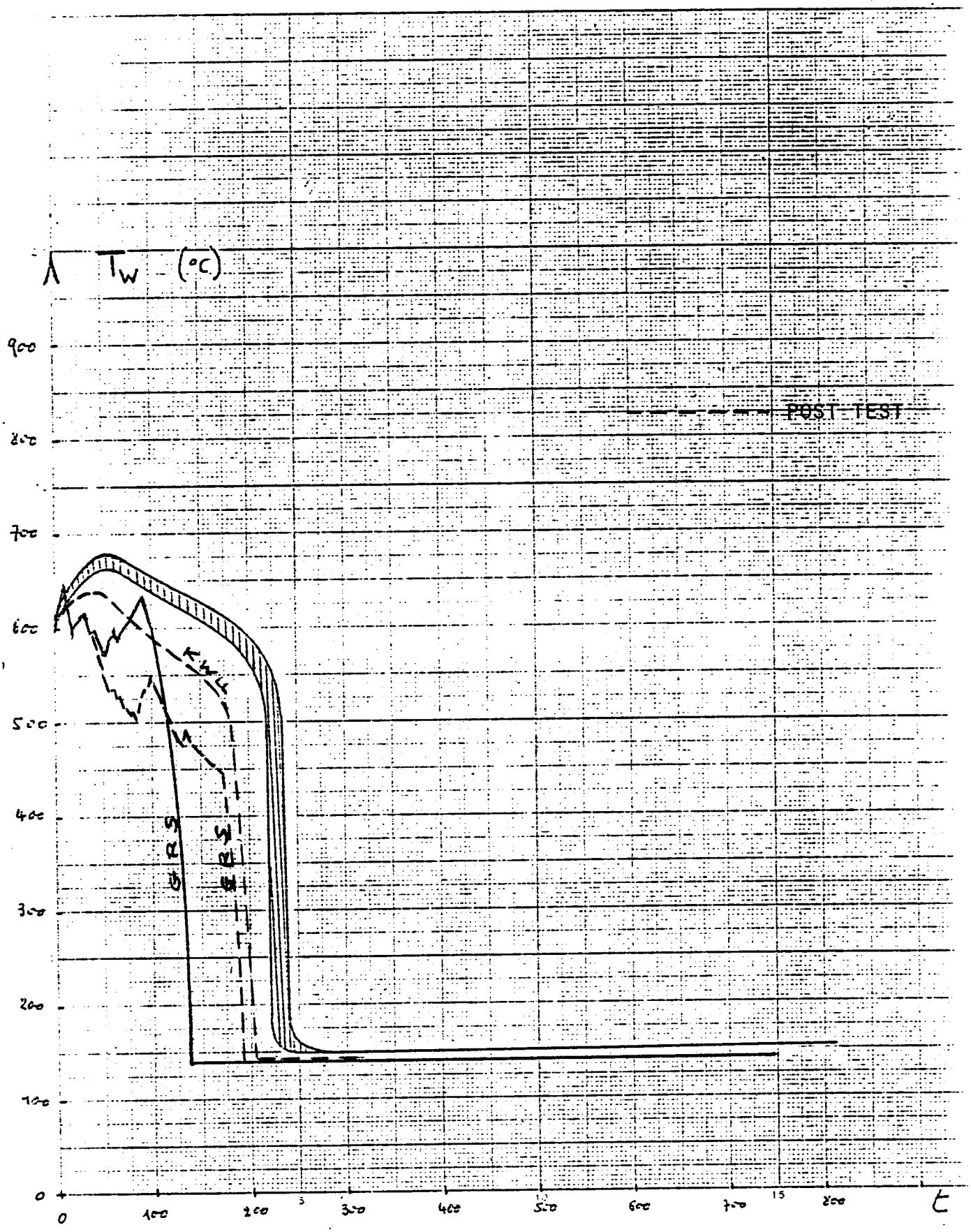
29 - Post test calculations with RELAP 4 mod 6
Wall temperature at 2.99 elevation.



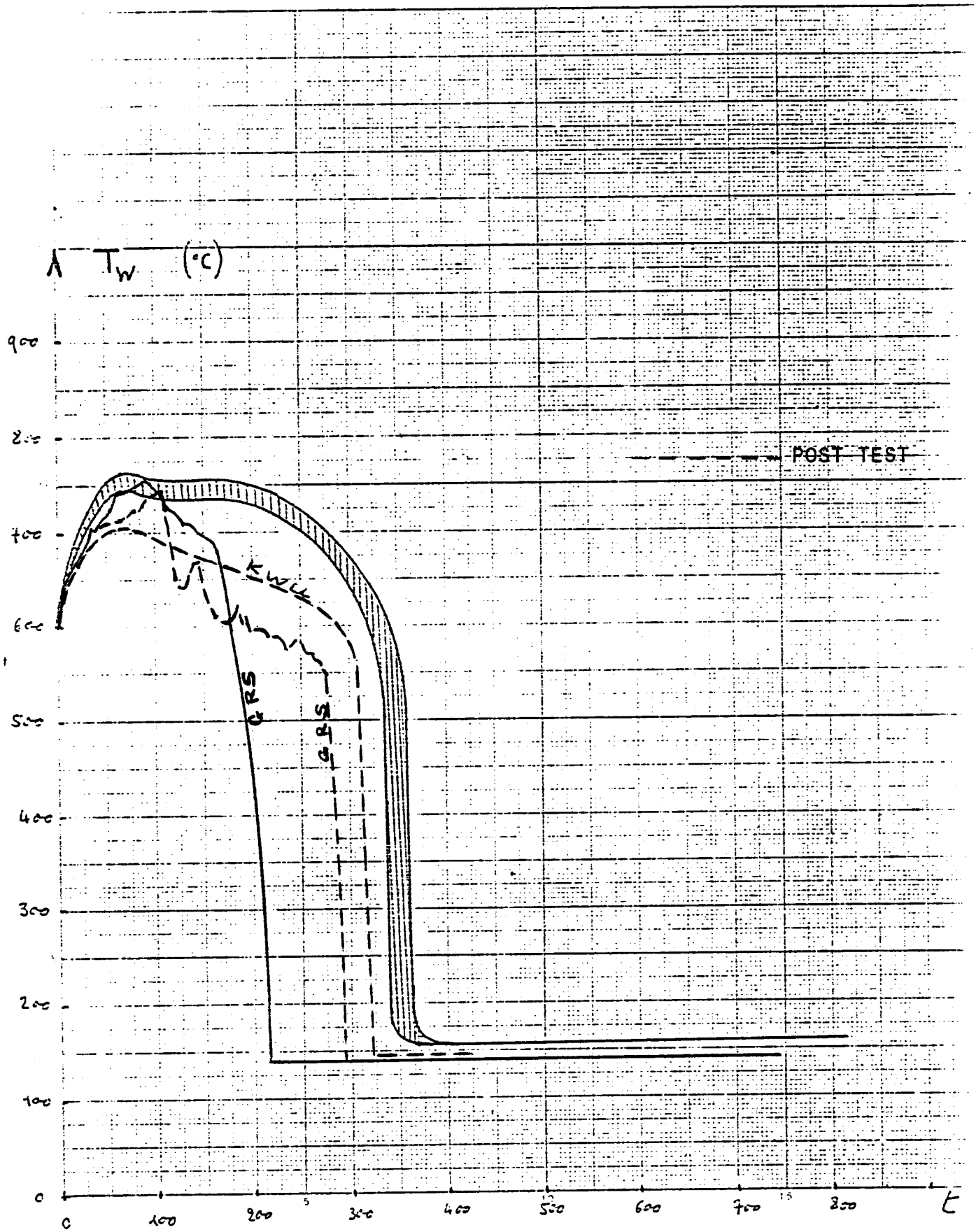
30 - Post test calculations with RELAP 4 mod 6
Quench time versus elevation.



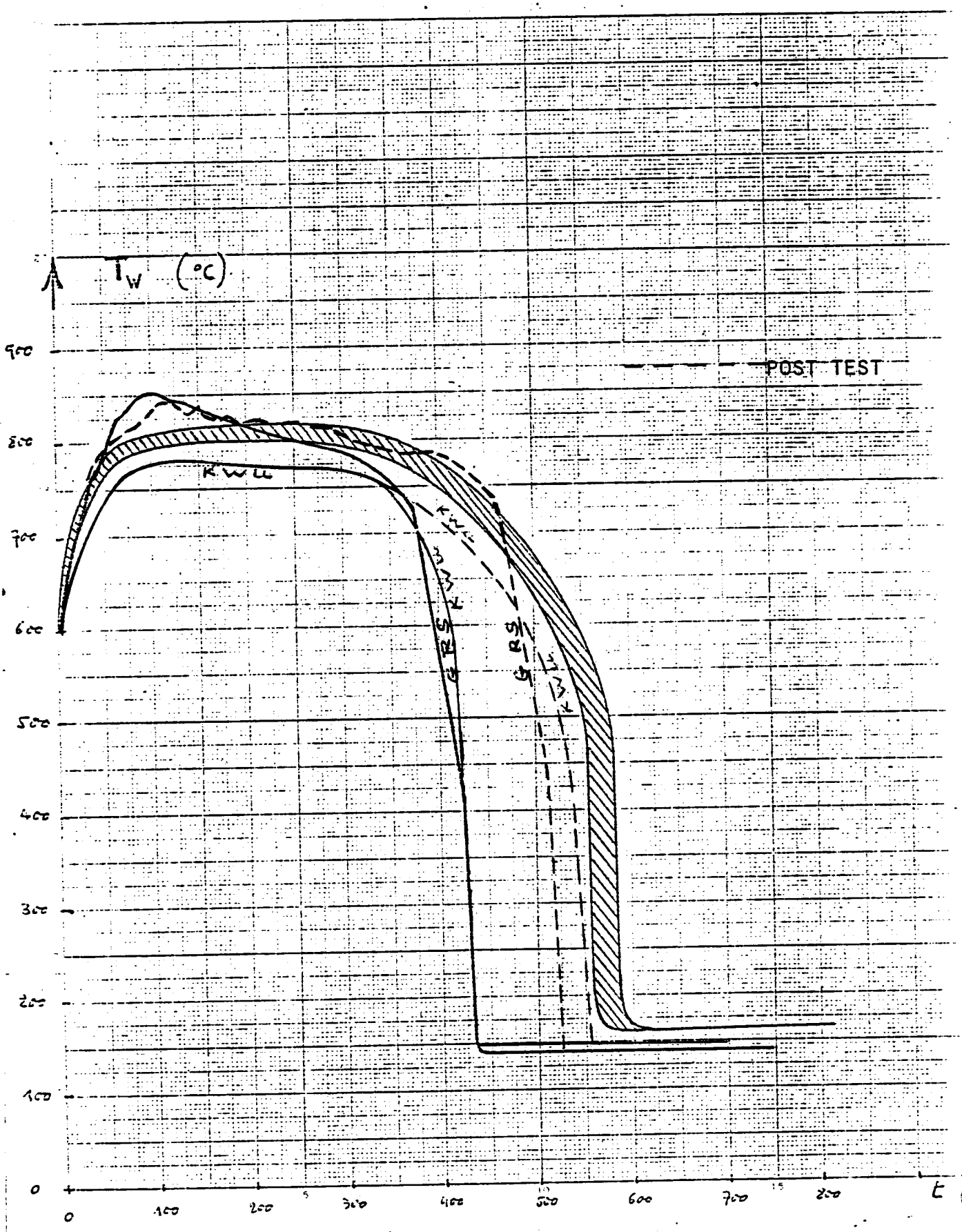
31 - Post test calculations with RELAP 4 mod 6
Mass flow rate of entrained water at the outlet of the test section.



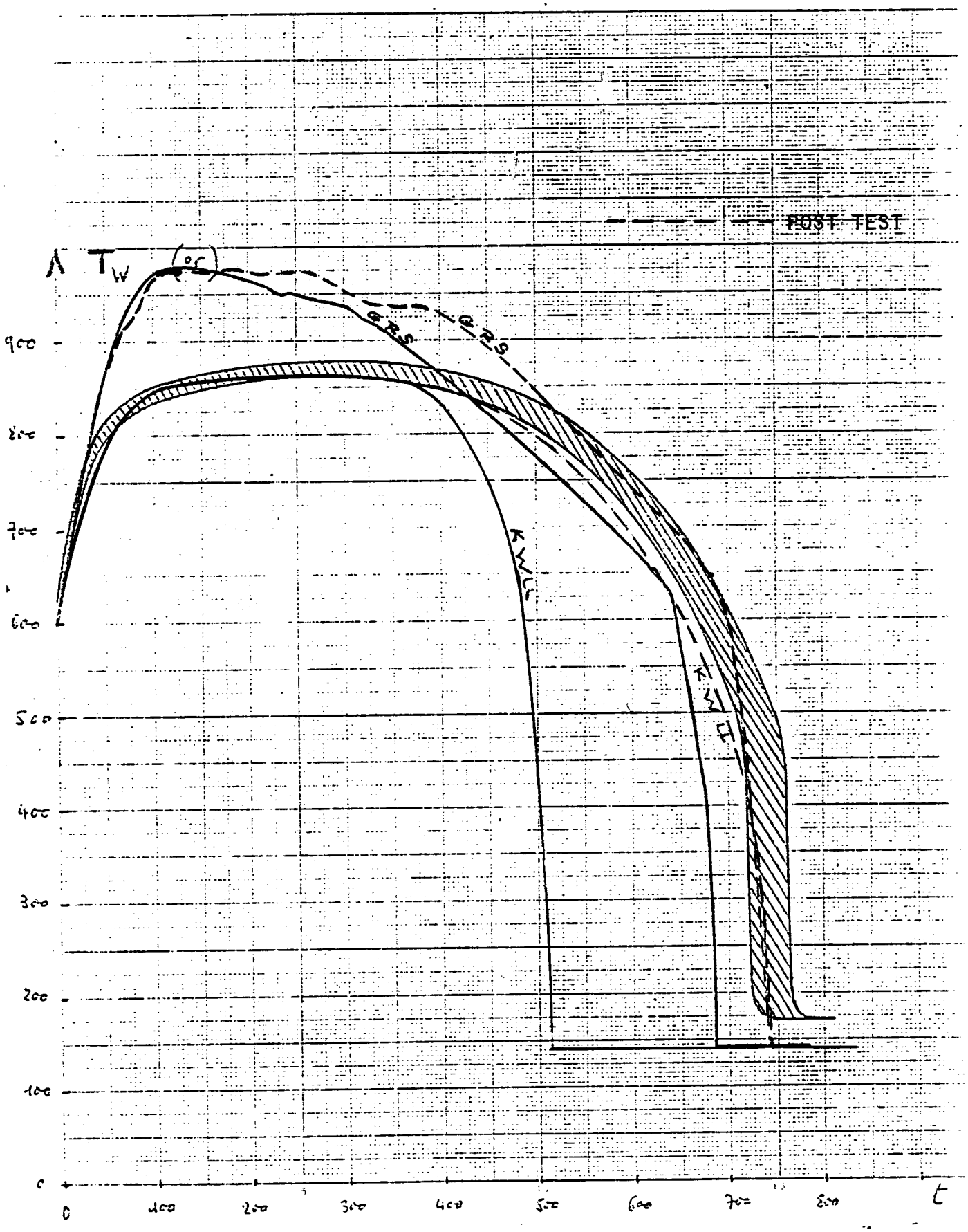
32 - Post test calculations from Germány
Wall temperature at 0.98 m elevation.



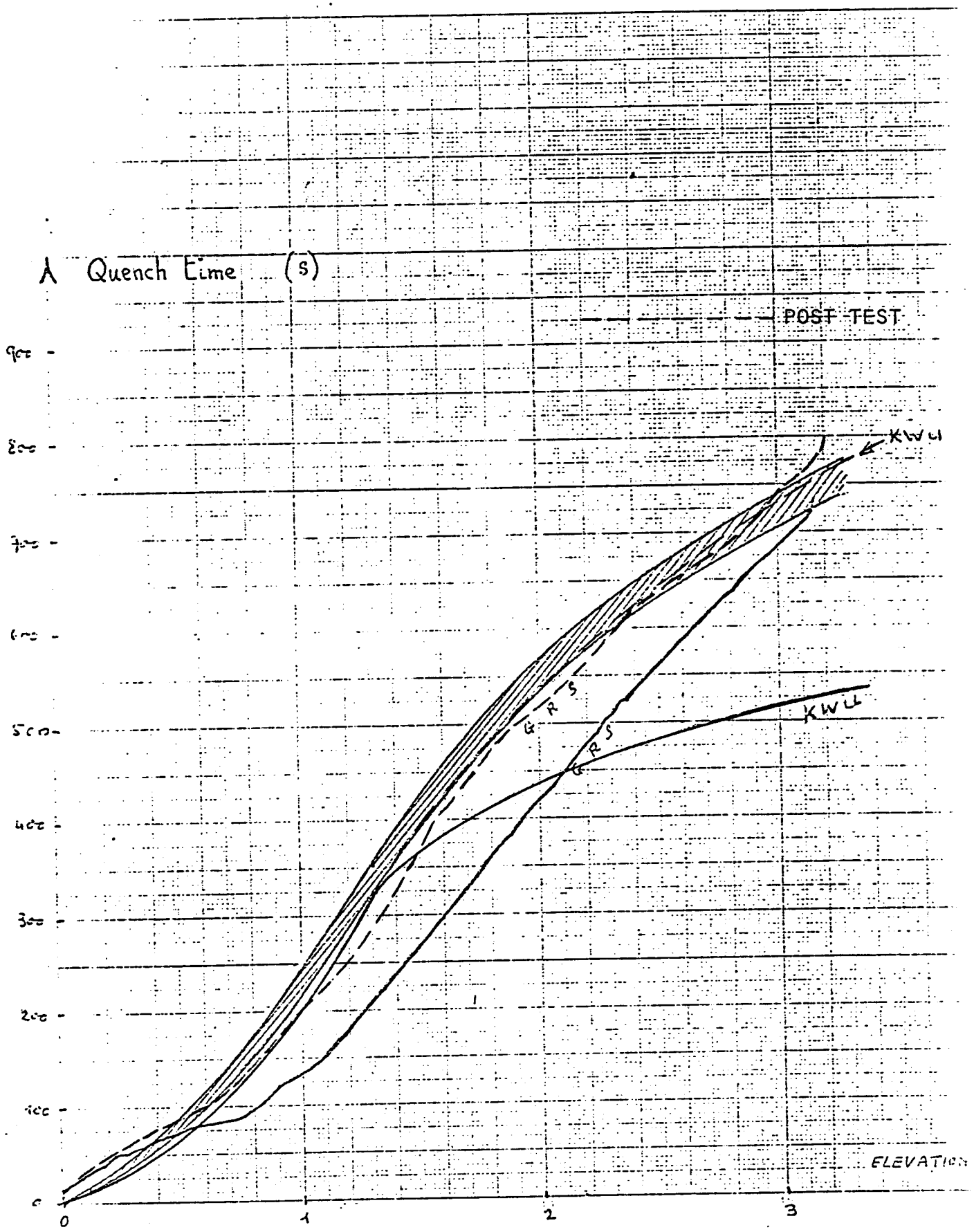
33 - Post test calculations from Germany
Wall temperature at 1.3 m elevation.



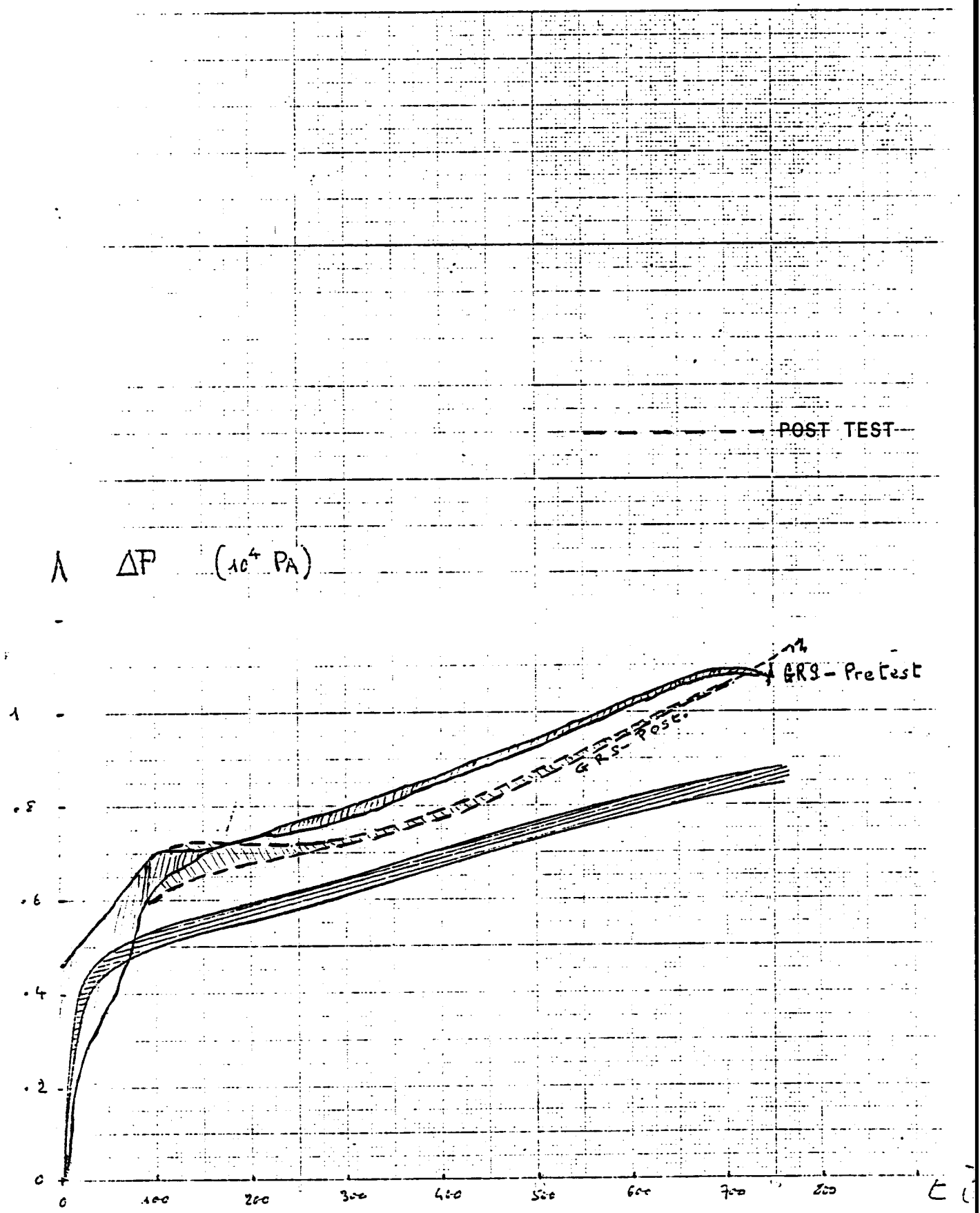
34 - Post test calculations from Germany
Wall temperature at 2.03 m elevation



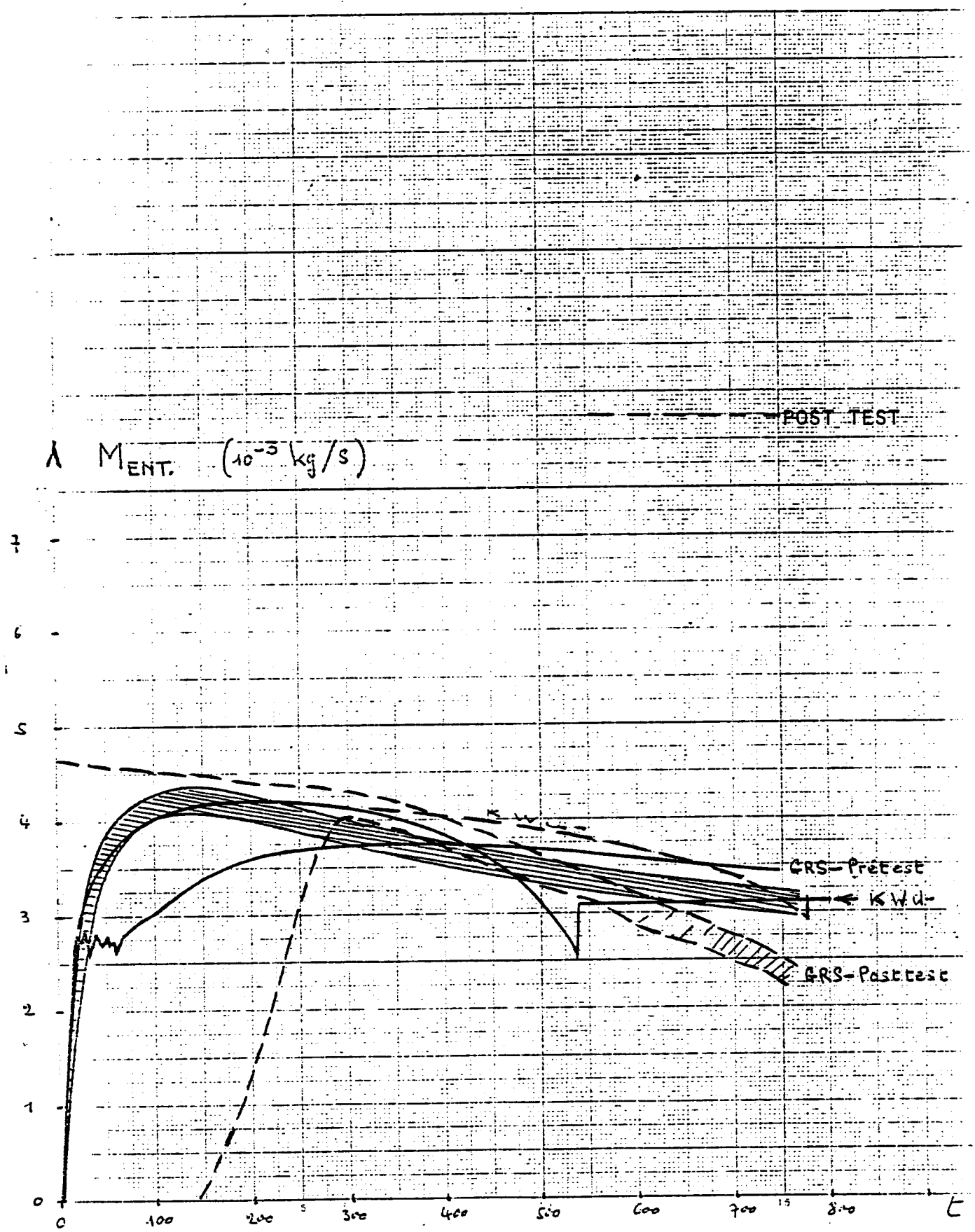
35 - Post test calculations from Germany
Wall temperature at 2.99 m elevation.



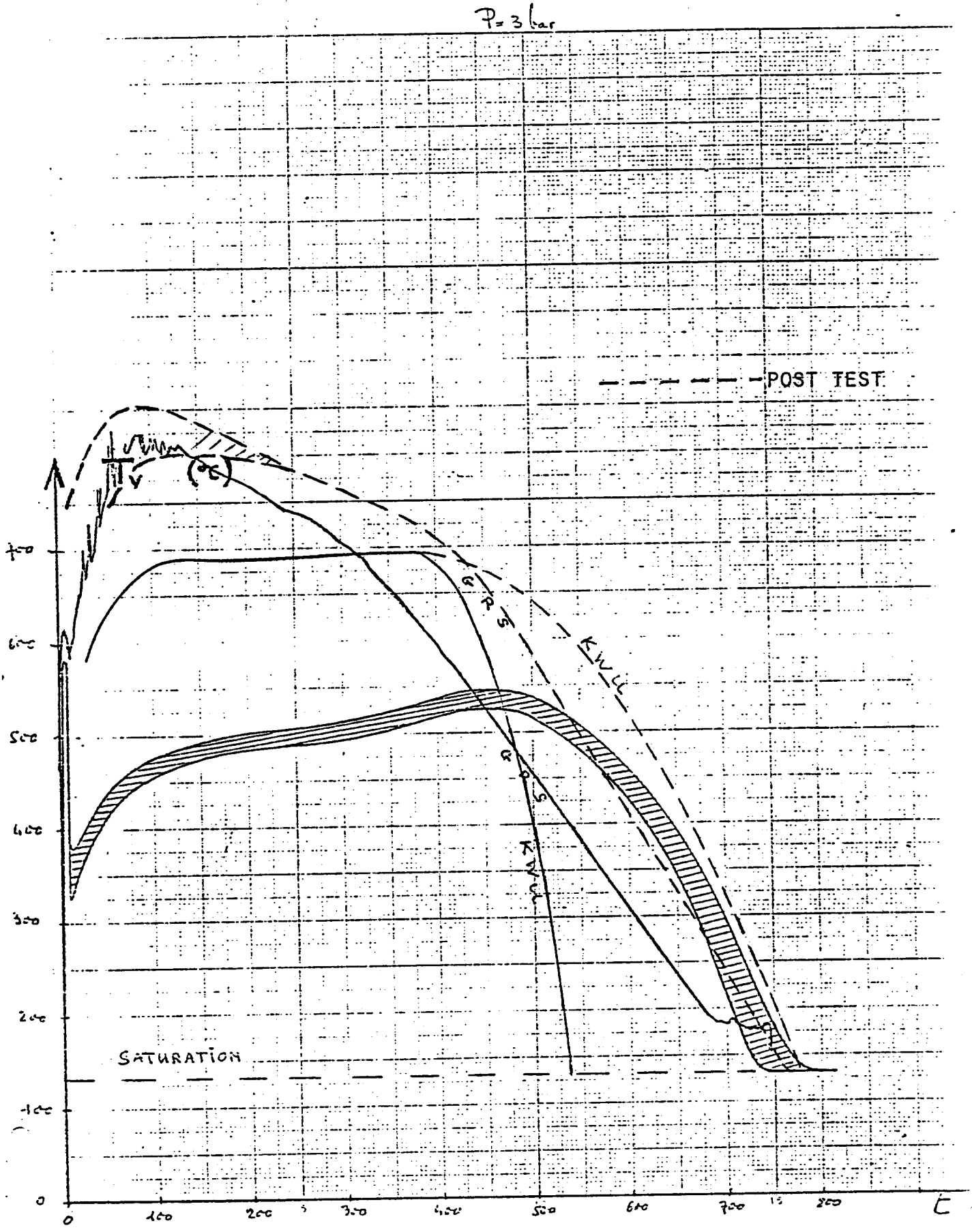
36 - Post test calculations from Germany
Quench time versus elevation.



37 - Post test calculations from Germany
Pressure drop on the heated tube length.

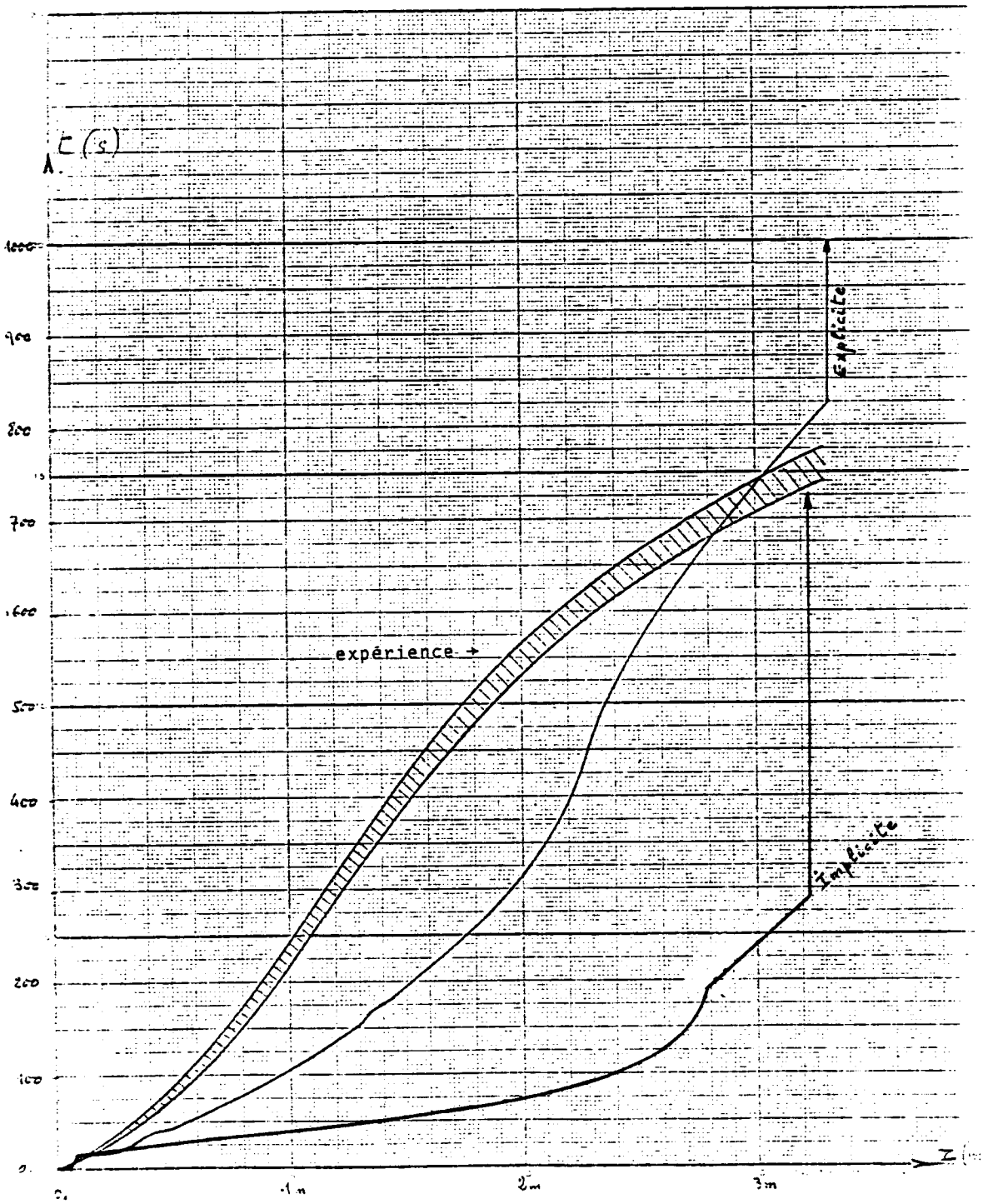


38 - Post test calculations from Germany
Mass flow rate of entrained water at the outlet of the test section.

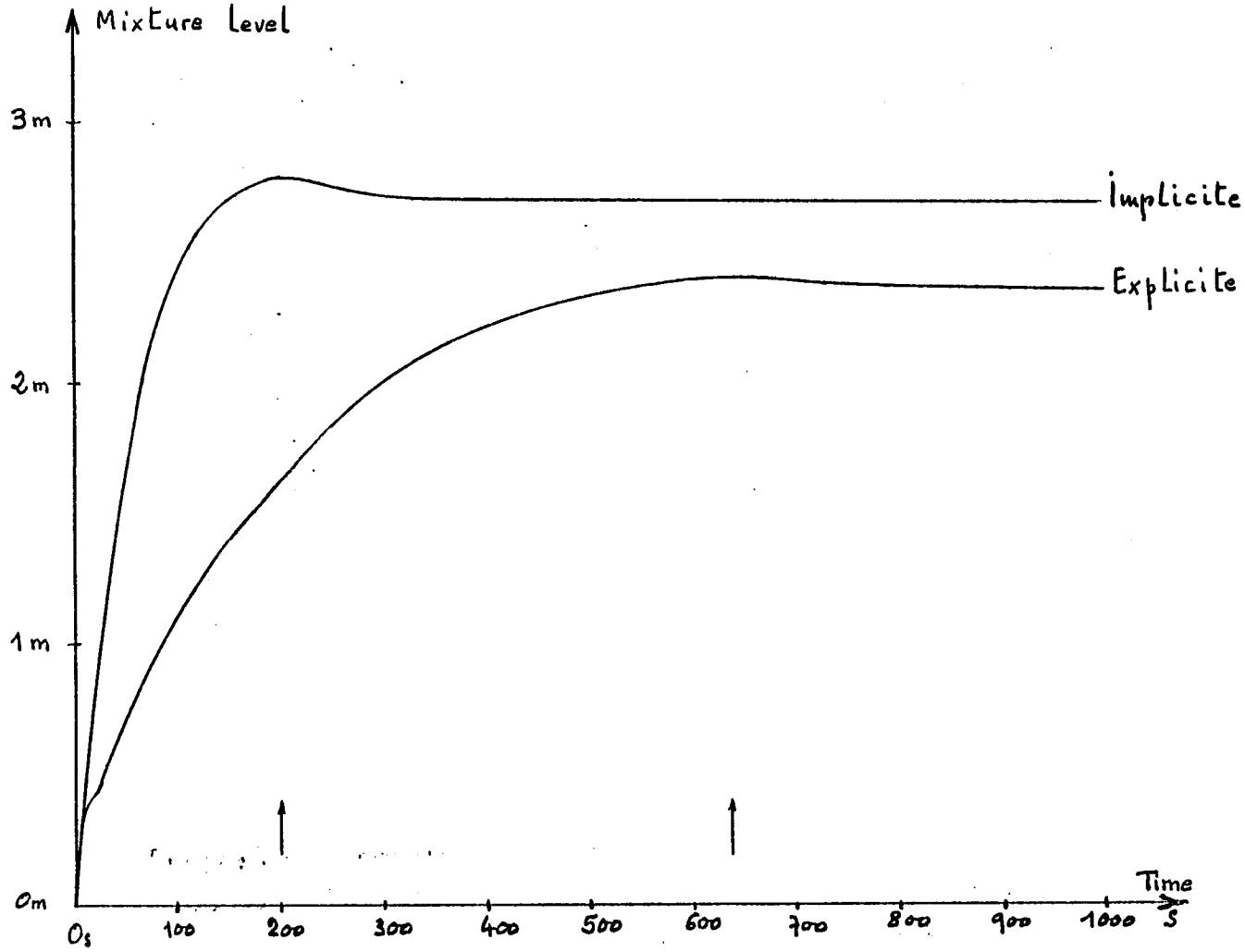


39 - Post test calculations from Germany

Steam temperature at the outlet of the test section.



40 - Quench time versus elevation calculated with two methods of numerical coupling.



41 - Mixture level history calculated with two methods of numerical coupling.