

International Energy Agency

# IEA District Heating

Programme of research, Development and  
Demonstration on District Heating and Cooling

BENDS FOR  
PLASTIC JACKET PIPE SYSTEMS  
ABLE TO WITHSTAND  
HIGH TRANSVERSE LOADINGS

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the IEA District Heating and Cooling project

INTERNATIONAL ENERGY AGENCY

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Demonstration on District Heating

**BENDS FOR PLASTIC JACKET  
PIPE SYSTEMS ABLE TO WITHSTAND  
HIGH TRANSVERSE LOADINGS**

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## ADDENDUM

ref. to report 1992:P4

The work was coordinated by the following group of experts:

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In the appendix to the report attached you will find important bibliographical references. They are cited in their original language. Please look at them not as a part of the report but as a service to the reader.

We apologize for the bad printing quality of appendix 1. It is not due to misprinting but due to the fact that printing was done from telecopies. The printing of just these diagrams was estimated to be essential, as these curves in the present version were discussed fiercely between experts.

page 13	Maximale Gleithereichshöhe Natürlicher Festpunkt	maximum sliding range automatic fixpoint
page 18	Nullproben bzw. Rückstellmuster Test- bzw. Versuchsröhre	no-test sections test sections
page 20	Vorderansicht, Seitenansicht	front view, side view
page 23	Querbelastbares EMR Druckspannungen Prüfabschnitte Breite evtl. Ändern auf 1,5 N/mm <sup>2</sup>	Transverse loadable PJP compression testsections width change possible to 1,5 N/mm <sup>2</sup>
page 26	FV "Betr. Selbstvorspannung" PUR-Schaum Kurzzeitversuch Normalschaum ohne FCKW Belastungsgeschw. Normalschaum mit FCKW	Research project "Prestressing" PUR-foam short-time test normal foam without CFC speed of loading normal foam with CFC
page 27	FV "Querbelastbares Rohr" PUR-Schaum Kurzzeitversuch Bihglasseschaum ohne FCKW Belastungsgeschw. Bihglasseschaum ohne FCKW	"Transverse loadable pipe" PUR-foam short-time test foam glass without CFC speed of loading foam glass with CFC
page 37	B = Breite Wandstärke Bogen,- Rohr Radius Anschweißende	width Wallthickness (bend), (pipe) Radius Weldend

Translations of special comments to figures

Figure 8-5	Weg Normal-Schaum mit FCKW Versuchstemperatur	displacement Normal foam with CFC Test temperature
Figure 8-6	Weg mit FCKW Versuchstemperatur	displacement with CFC Test temperature
Figure 10-1	Trasse 1 Teil 1 Trassenplan 1 M 1:1000 (nach Vergrößerung auf DIN-A3)	Section 1 Part 1 Sectionplan 1 Scale 1:1000 (DIN-A3 enlargement)
	Rohrleitungen im Schacht demon- tieren u. neu installieren	Dismantle pipe-systems in chamber and replace
	Anschluß an vorh. Leitung DN 65 im zu erweiternden Entleerschacht	connection to existing system in accordance with DN 65 chamber to be extended
	Anschluß an vorh. Leitung n. GEW-Zchng. FW 75/85-3.3	Connection to existing system in accordance with
	Reduzierg.	reduction
Figure 10-2	Trasse 1 Teil 2 Trassenplan 3 M 1:1000 (nach Vergrößerung auf DIN-A3)	Section 1 Part 2 Sectionplan 3 Scale 1:1000 (DIN-A3 enlargement)
	nach GEW-Zchng. FW91/87-3.1	in accordance with GEW drawing FW91/87-3.1
	Anschluß an vorh. KMR DN 150	Connection to existing KMR DN 150
Figure 10-4	Detail Wegmessung mit T-Stück aus PE-Rohr	Detail of Displacement Measurement with T-piece of PE-pipe
	Einbau unter Straßenkappe	Installation beneath service cover
	PE-Schrubdeckel	PE-Screw cap
	* von Fa. GEF für das For- schungsvorhaben "Neuartige Wärmeverteilung" entwickelt	developed by GEF within the scope of the investigation project "New Distribution Technology"
	Meß T-Stück aus PE-Rohr das Kunststoffmantelrohr muß unbehindert durch das PE-T-Stück gleiten können	measuring T-piece of PE-pipe the plastic jacket pipe has to be able to glide unimpeded through PE-T-piece
	Markierung auf KMR	Marking on plastic jacket pipe
	Meßband aufkleben bevor der PE-Stutzen verschweißt wird	Tape measure to be adhered before welding the PE-nozzle
	PE-Flansch	PE flange
	Achtung !	Important !
	Das PE-T-Stück darf sich nicht verschieben. Gut verdichten	The PE-T-pipe must not be dis- placed. Pack tightly.

Dear reader,

The Executive Committee of the Implementing Agreement on District Heating and Cooling is interested to improve the impact of the R&D activities and the effectiveness of the programme.

For that reason the Operating Agent needs your support. May I ask you to be so kind to complete the following questionnaire and to sent it back to:

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Attn. Mr. J.C. Resing  
P.O. Box 17  
NL-6130 AA SITTARD

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.....  
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0 How did you receive your copy of the report?

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0 Do you appreciate the activities, described in the report?

.....  
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0 Do you have suggestions for further dissemination of the results presented in the report?

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0 Do you have any suggestions for further tasks, or comments to the activities of the Implementing Agreement?

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.....

## 1. Summary

In international cooperation there has been developed a new component for the plastic jacket pipe system, which allows a design without "weak point" expansion pads and which makes it possible to realize any change in direction between 0 and 180°. This will lead to lower laying costs, to higher operational safety and - last but not least - to a longer service life.

The new component, for which GEW Köln applied an international patent, is based on a German invention. Today, it is manufactured by the Danish system manufacturer TARCO. The soil reaction which is the main basis for the design is based on series of measurements from the ASCE (American Society of Civil Engineers).

The bend able to withstand high transverse loadings is totally conformal to the system and is connected to the straight plastic jacket pipe with the usual joint - just like a standard pipe. A leak detecting device may be kept inside the bend, too.

The bend's ability to withstand higher transverse loads is due to a reinforcement of the foam with expanded glass beads. This reinforced foam has a permissible compressive stress which is 10 times higher than that of the non-reinforced foam. Therefore, bends able to withstand high transverse loadings can definitely withstand the soil reactions which occur as a consequence of the transverse displacements of the pipe.

The PUR-foam has to be reinforced only in those sections, where the radial compressive stress is too high for normal foam. Due to the high soil reaction, the transverse displacements decline already after a short distance. In case of smaller and medium diameters only slightly lengthened, reinforced bend sides are required. Normally, bend leg lengths of 1 to

1.5 m are sufficient.

After 3 years of testing in laboratories and pilot plants the new components are considered ready for the market and are applied in several European test sites. A systematic test is carried through at two test sites in Cologne applying cold laying DN 150 to DN 40. Here, occurring displacements of the system are collected with mm - accurates. Besides, the steel stresses are measured both, in longitudinal and in circumferential direction, at the highest loaded cross-sections at 8 circum-ferential points with the help of wire strain gauges.

A further application will take place in 1992 with cold laid lengths DN 300 in Copenhagen. Here, the occurring forces and displacements are reduced by lowering wall thickness of the straight pipe.

The bends for plastic jacket pipes able to withstand high transverse loadings are able to take up - under coexisting load and temperature - high radial compressive stresses.

Here, the non-ageing expanded glass foam transfer the forces starting from the medium pipe onto the plastic jacket pipe. In case of the new bends for plastic jacket pipes able to withstand high transverse loadings, the function of the foam, which loses most of its resistance characteristics under temperature and time, is reduced to the bedding of the beads. There is good hope that the plastic jacket pipe's service life can be increased by the application of bends for plastic jacket pipes able to withstand high transverse loadings in the area of changes in direction, and can help to reduce the costs.

Regarding its technical and economical advantages it has to be assumed that the new component will soon prove its worth in the market and that it will be applied more often from 1993 onwards.

## 2. Earlier Design of Bends and Angular Deviations

Today, most of the district heating pipelines are manufactured as plastic jacketed pipes. These consist of a steel medium pipe, a thermal insulation of PUR-foam and a HDPE jacket pipe. Characteristic feature of this design is the fact that district heating networks are conceived for a service life of 30 to 50 years and that the statically stressed plastics - due to the influence of age and time - are subject to strong ageing. Therefore, for design of the plastic components, material properties which are reduced due to ageing have to be applied.

Regarding the normal maximum medium temperatures between 90°C and 140°C, the transverse loads may act on the PUR-foam at a very small extent. In case of high outgoing temperatures such as 130° or 140°C , the necessary permissible compressive strain of the PUR-foam is as high as = 0.15 MPa. Accordingly, the transverse displacement occurring at bends has to be absorbed in cavities (expansion unit) or in expansion pads (foamed cushions) in order to protect the pipe against high soil resistance forces. For conventional plastic jacket pipes, angular deviations have to be limited to maximum values of 3° and 6°, depending on the line situation.

### 3. Scope of the Study

In spite of the constructional improvements, expansion pads are regarded as "weak points" of the plastic jacket pipe system for several reasons:

- So far, the long term operativeness of the expansion pads has not been proved.
- Expansion pads constitute an additional thermal insulation which causes that the plastic pipe's jacket temperature is increased.
- When the expansion pad is compressed, considerable reset forces are activated, which cause a considerable load on the steel service pipe and PUR-foam.
- At road sections, the application of expansion pads causes additional problems, because the recommended bearing capacity cannot be reached at road surface level if the depth of covering is low.
- Large pipe diameters and non-preheated piping result in large expansions and large variations of expansion zone lengths. In most cases those expansions cannot be absorbed inside the expansion pads, because the permissible expansion pad thicknesses are limited by soil mechanics and heating up of the PE-jacket.

Another problem are the angular deviations between about 8° and 80°, which normally cannot be realized with the former plastic jacket pipe system. This makes it either rather difficult to find the lines, or cost intensive compensation elements are required.

#### 4. Aim of the Study

Part of the investigation project "New Testing Techniques and System Components at the Plastic Jacket Pipe", carried through by Gas- Elektrizitäts- und Wasserwerke Köln AG (GEW) is to exclude out the usual expansion pads at bends.

GEF (Ingenieurgesellschaft für Energietechnik und Fernwärme GmbH) which is entrusted with the performance of the study, assumed that this was not possible with the usual components of the plastic jacket pipe, because the increased loads cannot be withstood by neither the sleeve joints, nor the foam or the steel pipe.

Therefore, pipes have to be developed which can be loaded especially in transverse direction and which, with permissible stresses, can carry these loads. For this purpose, the development of a foam with high radial compression resistance takes the limelight. Such "polyurethane-lightweight concrete" would have to be able to transfer the transverse loads, which are caused by the bedding reactions at the changes in directions, to the medium pipe during its total service life.

##### 5. Load on Directly Buried Bends without Expansion Pads

The soil resistance which is caused by the horizontal transverse displacement of pipes embedded in soil is known from systematic series of tests carried out by the American Society of Civil Engineers (ASCE) [1]. For these tests, sand-bedded pipes were displaced horizontally under clearly defined conditions, and the transverse compression  $Q''(v)$  was outlined on the displacement way  $v$ . It was found out that the earth's bedding reaction depends on the following factors:

- burying depth
- external diameter of the pipe
- soil density
- degree of compression

In [1] equations for various filling floors were formed for  $Q''(v, d_k, h_k)$ , showing a good agreement with the measured values.

A typical bedding characteristic is shown in Figure 5-1. In case of a certain transverse displacement  $v$ , the maximum soil resistance is reached and cannot increase anymore, even if the displacement is getting larger.

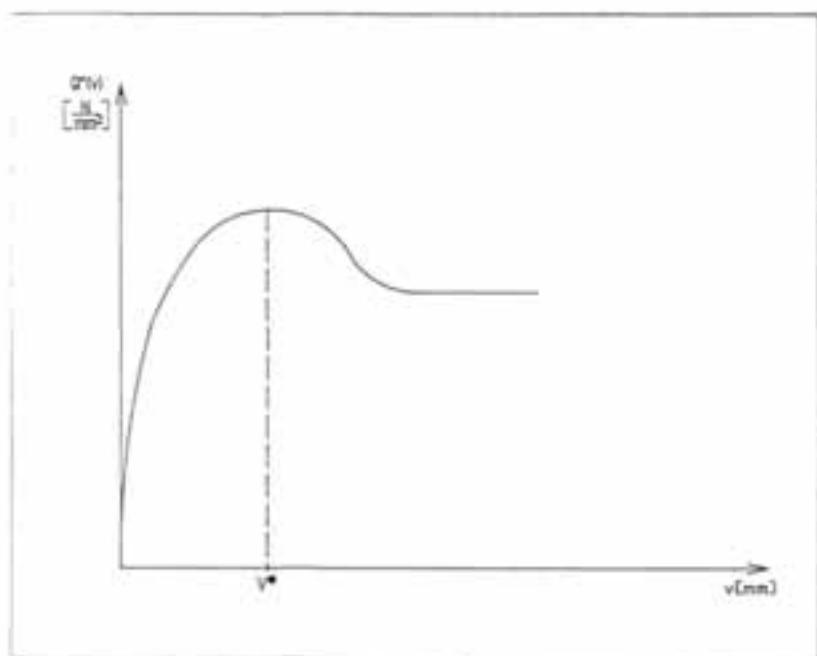


Figure 5-1: Soil Restraint Reaction [1]

In the calculation program GEFKMR [2], bedding characteristics of the soil is introduced as a default value, paying attention to the above-mentioned influencing variables. The decrease of the soil resistance after exceeding  $v$  is not utilized for safety reasons.

The ASCE-investigation [1] shows that under high values of  $h_0/D_N$  (large depth of coverage or small pipe diameters) local yield zones occur close to the pipe at the compression side. Those zones do not show any effects at the surface of the ground. If the depth of coverage is smaller (small values for  $h_0/D_N$ , elliptic yield areas are formed which lead to wedges or archings of the surface (see Figure 5-2).

Reinforced roads do not allow such archings of the surface and force local flow zones in front of the pipes.

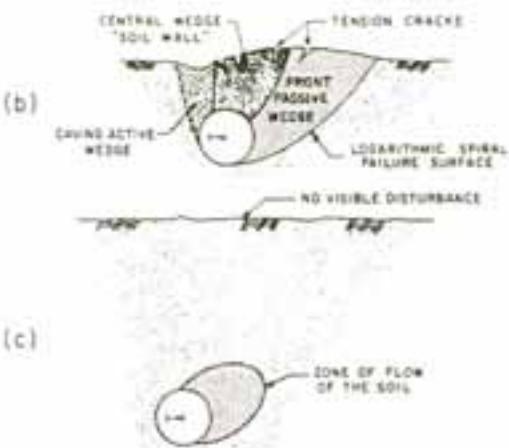


Figure 5-2: Soil flow zones as a result of horizontal displacement of pipes in the soil [1]  
b) with low depth of coverage  
c) with large depth of coverage

Therefore, road reinforcements have an effect similar to depth of coverage. As the ASCE-investigation did not study the influence of road consolidations, the theoretical depth of coverage is generally increased by 0.5 m in the GEFKMR-program for the determination of the soil resistance. This value may be changed by the user, in case there are new findings.

If there is no road consolidation it is advisable to increase the theoretical depth of coverage in order to determine the soil resistance under consideration of the PUR-compressive strain in radial direction and the circumferential bending stress of the medium pipe.

The GEFKMR-program names three types of soil:

- 1 slightly compressed soil
- 2 medium compressed soil
- 3 highly compressed soil

These groups correspond to the following soil characteristic values.

Type of Soil	$\varphi$ [°]	$\gamma$ [k <sub>n</sub> /m <sup>3</sup> ]	D <sub>pc</sub> [%]
1	33	16	95
2	36.5	16.8	97.5
3	40	17.6	100

with

$\varphi$ : Angle of internal friction

$\gamma$ : Unit weight of soil

D<sub>pc</sub>: Compaction density

Figure 5-3 shows the occurring transverse compression Q" (v) according to [1] for a pipe of DN 100, with outer diameter D<sub>x</sub> = 200 mm and h<sub>a</sub> = 0.5 m in highly compressed soil. For this purpose, it was assumed that there is a road covering above the pipe line which increases the theoretical depth of coverage for the determination of the transverse compression from 0.5 m to h<sub>a</sub> = 1 m, as it was assumed before.

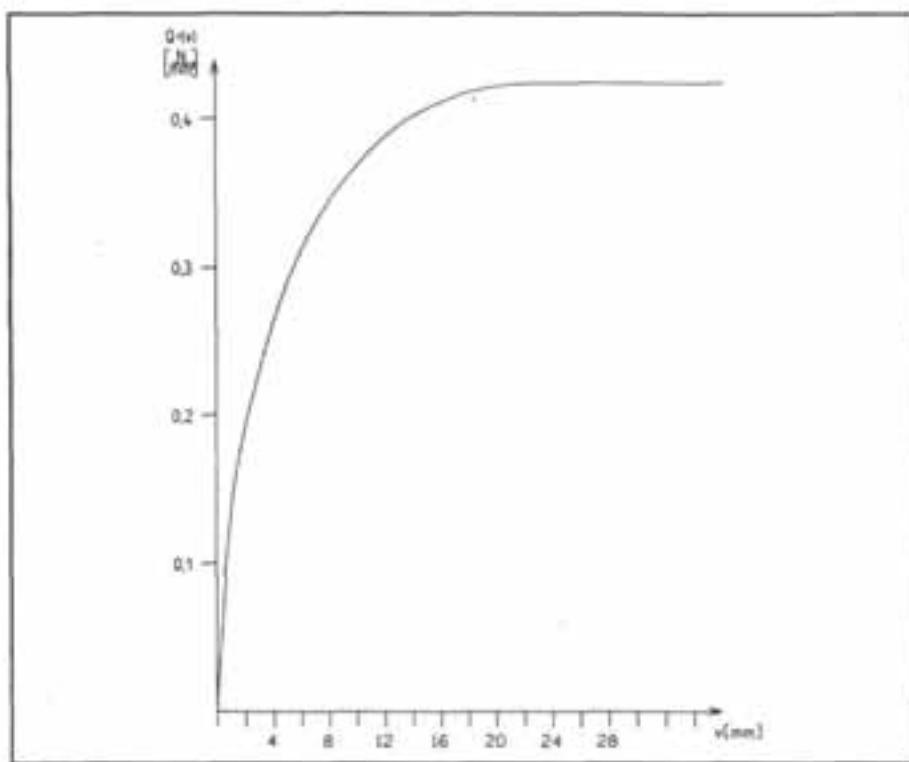


Figure 5-3: Transverse Compression  $Q''$  ( $v$ ) for DN 100,  $D_s = 200$  mm,  $h_a = 0.5$  m ( $h_a = 1$  m) in highly compressed soil

Prior to the actual development, the maximum possible loads to be expected were calculated by orientation calculations.

Therefore, isosceles L-systems with maximum variation zone lengths were taken as a basis, the sectional forces of which and the displacements were calculated with a special finite element program for plastic jacket pipes, paying special attention to friction and transverse soil resistance. Figure 5-4 shows the system lay out for the load calculations.

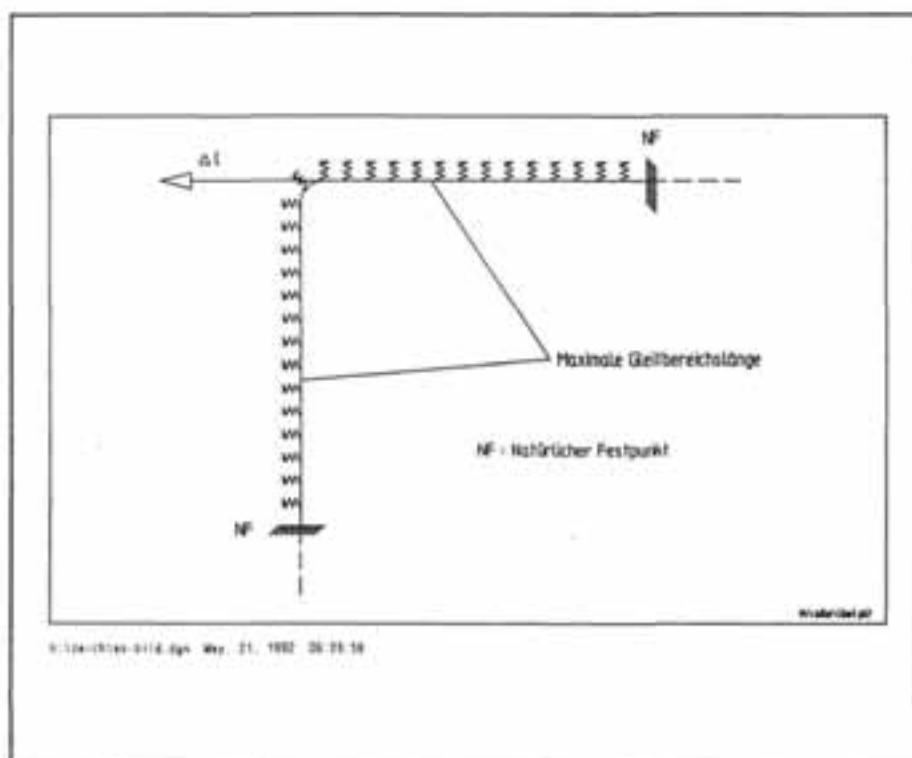


Figure 5-4 : Static System

Due to the soil bedding pressure acting directly on the plastic jacket pipe, the final displacements could be reduced to 50% compared to the displacements appearing in the design when expansion pads are used. As a consequence of the high bedding forces, the bending line declines after a short distance right after the bend. With DN 32, there are no transverse displacements to be found 1 m from the mid-point of the bend, which means that there are no increased radial compressive strains either. With DN 200 the length of declination is about 2 m.

This led to the conclusion that the bends for plastic jacket pipes able to withstand high transverse loadings to be developed should be able to bear radial pressure loads as high as 1 N/mm<sup>2</sup>, with side lengths of 1 to 1.5 m, depending on the pipe diameters.

## 6. Development of Standard Types

For the research and development project it was tried to develop bends able to withstand high transverse loadings, attached to the plastic jacket pipe system.

The behaviour of the new developed plastic jacket pipe bends is due to the fact that for the first time PUR-foam is applied for district heating pipelines, which is reinforced by expanded glass beads or clay, which shows a many times higher ra-dial compression strength even when it is aged. The expanded glass or clay beads, filled in with a compactness as high as possible, form a bearing skeleton between medium and jacket pipes causing that the transversal load bearing capacity of the pipe becomes independent from load period and the medium temperature. Here, the function of the foam, which loses a great part of its resi-stance characteristics under the influence of temperature and time, is reduced to the bedding of the beads.

Figure 6-1 shows the structure of a transverse loadable plastic jacket pipe in its profile.

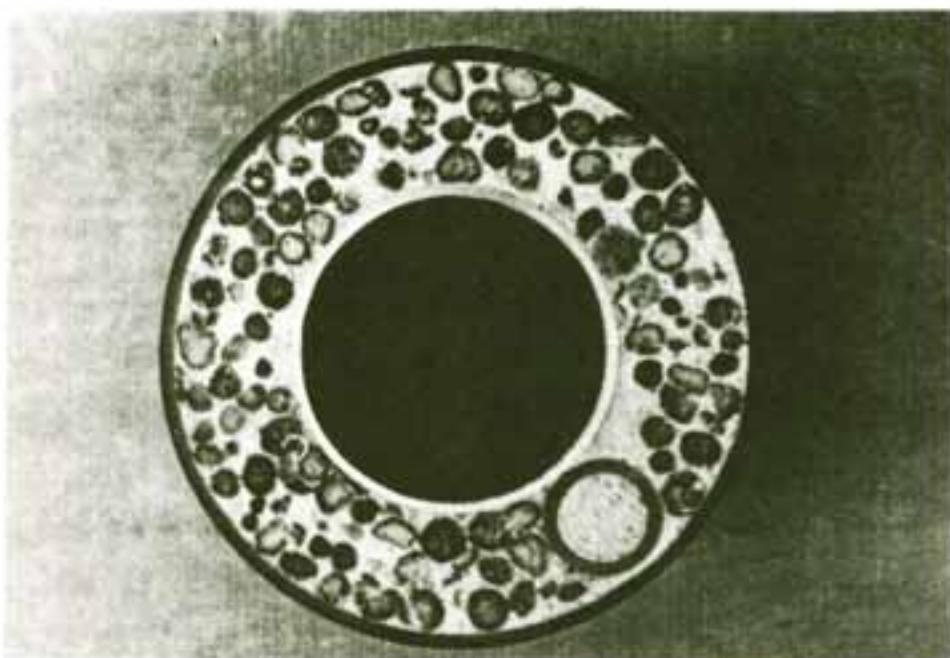


Figure 6-1: Sectional view of the transverse loadable plastic jacket pipe (first Standard Type).

For the manufacturing of these transverse loadable components the insulating space has to be filled as compact as possible with expanded clay or glass beads prior to foaming. For this purpose, the medium pipe is exposed to vibrations generated by a vibrator. Special regard was paid that the beads have a possibly round form and a uniform ball diameter. Given a ball diameter of about 10 mm, which is ideal for small and medium pipe diameters, it is guaranteed that on the one hand, a stable skeleton is formed and on the other hand there are cavities available which are large enough for the foaming procedure.

Due to the impeded flow, the subsequent foaming requires special techniques. One possibility is to place a one-way foaming pipe (see Figure 6-1, bottom) of plastic or metal and with perforations into the ring zone between medium and jacket pipe, prior to the filling with expanded glass beads. This helps to shorten the flow length.

Meanwhile a special foam-filling technique has been developed which means that the foam is filled in under high pressure and without using a foaming pipe from the middle of the building element. Afterwards, the opening in the HDPE jacket pipe is welded already at the factory (see Figure 6-2). In this technique is no one-way foaming pipe necessary.

Elements for plastic jacket pipe systems able to withstand high transverse loadings should be applied only in those strict heating sections which are exposed to considerable transverse load, i.e.

- bends
- angular deviations
- T-pieces

In view of the increased bedding reactions of the soil, only welded sockets should be applied for the connection of the jacket pipes. Still, the building elements, i.e. especially the bends, will need longer side lengths compared to conventional building elements, so that the joints may be laid in areas with less transverse load.

In transverse loadable pipe-components the steel pipe is more loaded, too. Some cases may require increased wall thicknesses or types of steel with higher yield-stresses.



Figure 6-2: Actual type of pipe able to withstand high transverse loadings.

## 7. Test Arrangements

The tests were carried out at two types of pipes: a) straight pipes of 1 m length with transverse loadable foam and b) pipe bars of 6 m length with normal foam.

The 6 m long normal foam pipes were sawed into 7 pieces, each being 0.8 m long, leaving out the end-pieces which are 0.2 m long (Figure 7-1). In view of a continuous diffusion protection, longer pipe sections should be preferred. Under the chosen length of 0.8 m the planned loads can easily be taken up by the elastic areas of pipes with normal wall thicknesses of the service pipe. This makes any special production superfluous, and pipes out of the normal manufacturing can be used for the tests. On each section the pipe number and the section's position along the flow displacement has to be indicated.

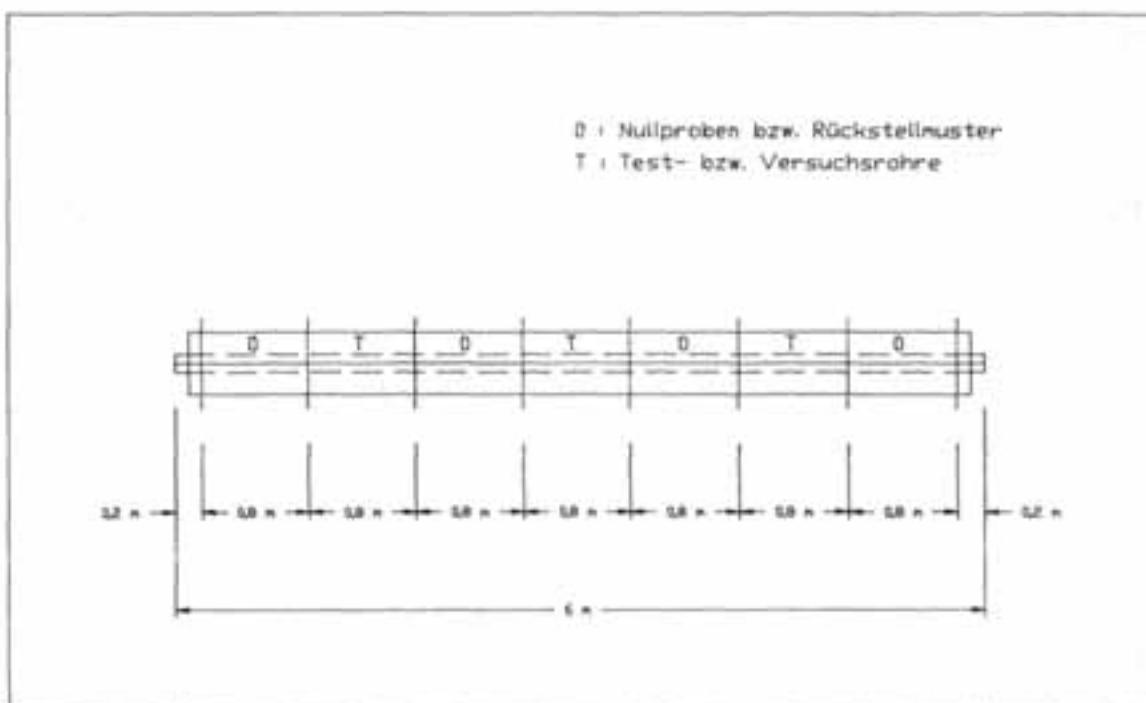


Figure 7-1: Cutting a 6 m long pipe into 7 test specimens

The pipe sections 1, 3, 5 and 7 marked in Figure 7-1 with a 0, are used as 0 specimens respectively are left over for the short-time tests.

Sections 2, 4 and 6, marked with a T, are now prepared together with the transverse loadable test pipes for the stress-rupture tests.

The test which decides on the pipes' suitability is the compression test under concurrent load, temperature and time (creep compression test). In order to complete the investigation results and to procure that there is a possibility for a sampling inspection within the scope of quality assurance, there were also short-time tests carried out, beside the stress rupture tests. All tests comprised the following pipe DN 80:

- normal foam without CFC <sup>11)</sup>
- normal foam with CFC
- expanded glass foam without CFC <sup>11)</sup>
- expanded glass foam with CFC

<sup>11)</sup> CO<sub>2</sub>-foam, state of development 1989.

#### 7.1 Short-Time-Tests

The following short-time tests were carried out in order to have a simple test method for the quality of the PUR-foams to be applied for operation compared to PUR-foams which were subject of the described tests:

- compression test
- TMA (Thermo-Mechanical-Analysis)

### 7.1.1. Compression Test

The experimental arrangement is shown in Figures 7-2 and 7-3. The pipe pieces were exposed to pressure load on a compression-tension-device, the speed of load application being 10 mm/min.

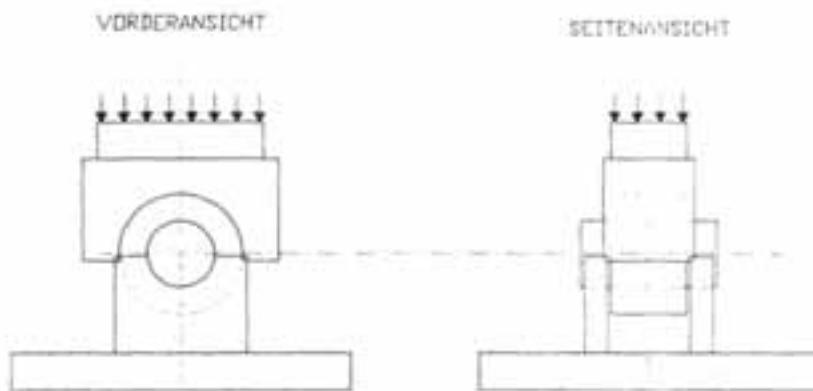


Figure 7-2: Placing of the pipe and load application for the compression test

The load probe's length is 100 mm, the projected area of the medium pipe  $88.9 \text{ mm} \times 100 \text{ mm} = 8890 \text{ mm}^2$ .

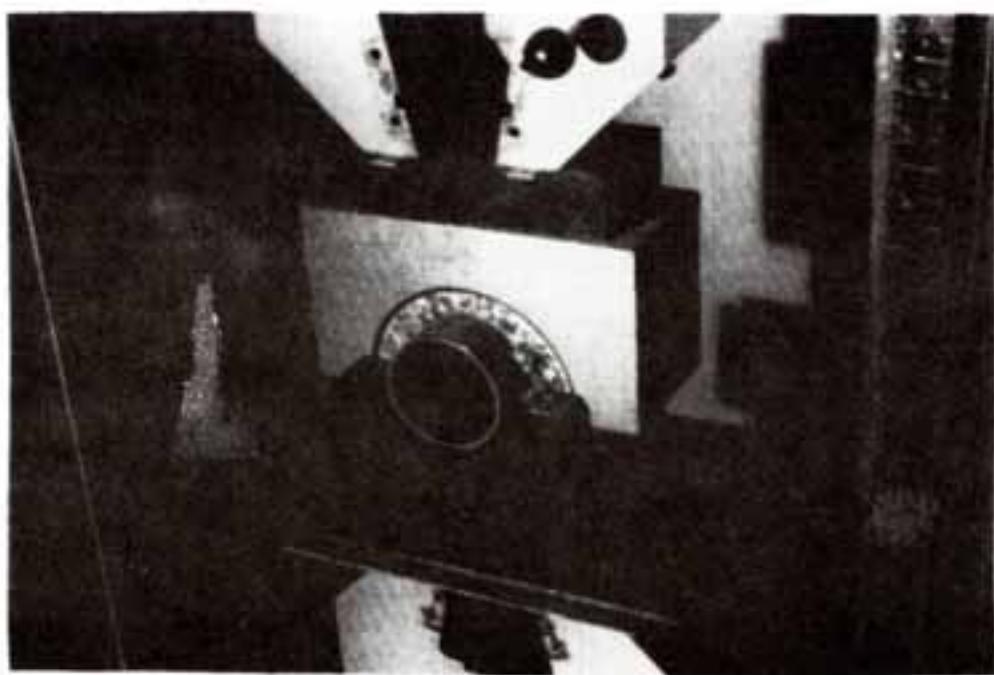


Figure 7-3: Test pipe with expanded glass foam during short-time test

### 7.1.2 TMA (Thermo-Mechanical-Analysis)

Foam specimens were taken out of the foam, being then subject to a thermo-mechanical-analysis, see Figure 7-4.

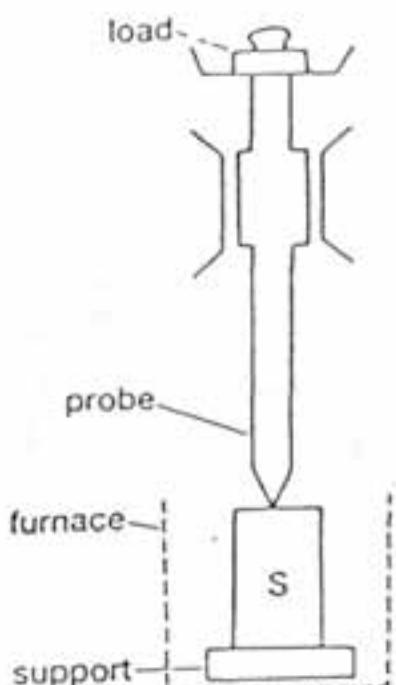


Figure 7-4: Schematic diagram of the TMA

### 7.2. Radial Creep Compression Tests

The renunciation of expansion pads causes a long lasting force effect upon changes in direction (ageing under load). Therefore, the pipes reinforced with expanded glass beads were subject to a radial creep compression test. For this test the actually occurring loads were subjected to increased temperatures in order to reach an acceleration effect.

There were 80 cm long straight pipe sections DN 80 placed onto the medium pipe and divided into 5 test steps. These test steps were loaded with radial compressive strains of 1, 1.5 and 2 MPa. Figure 7-5 shows the compressive strains for the creep compression test.

## Querbelastbares KMR

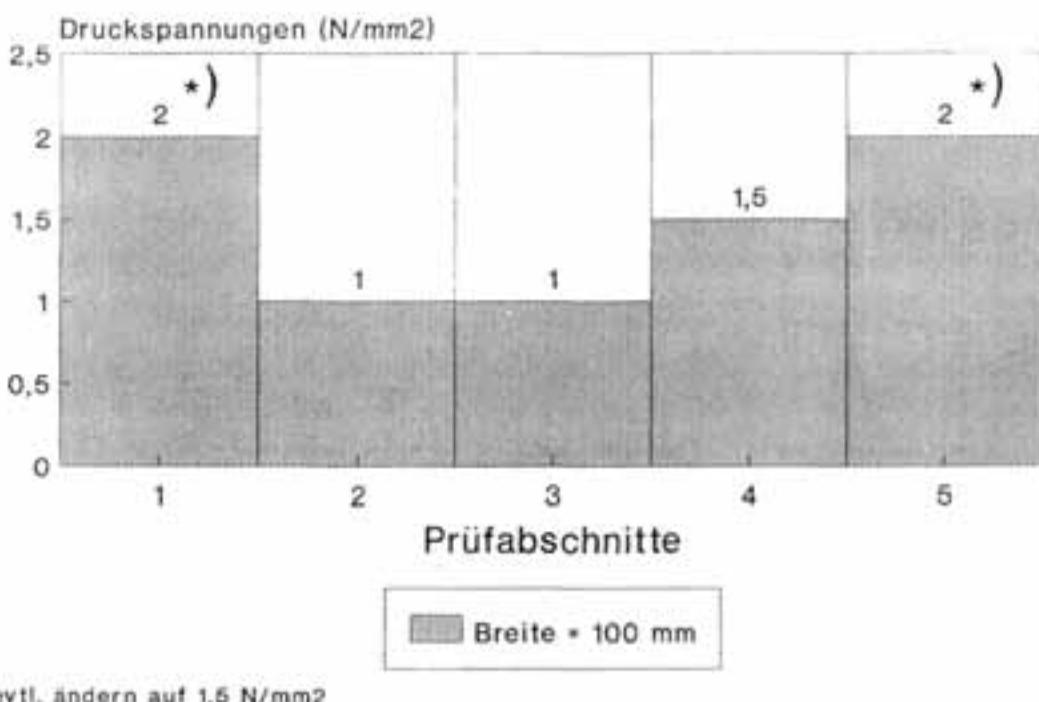


Figure 7-5: Load distribution for the creep compression test

The loads are transferred by lever arms to sheet steel loops which are placed around the plastic jacket pipe (see Figure 7-6).

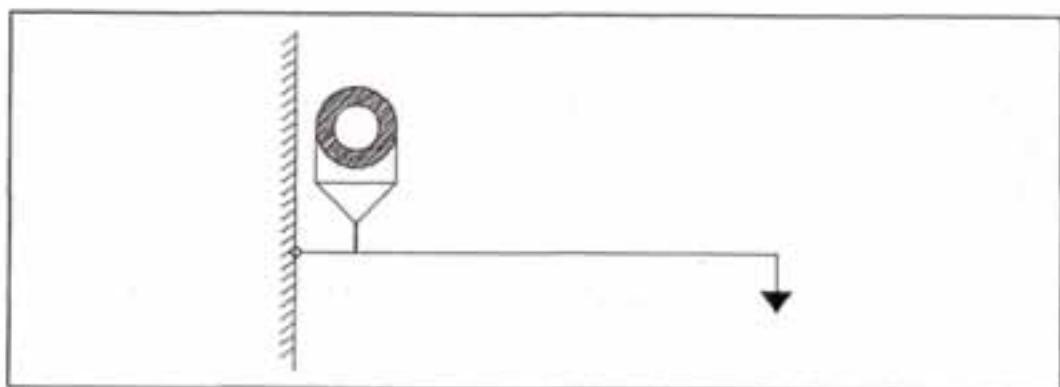


Figure 7-6: Load introduction by lever arms.

The tests were carried out under three different temperatures, i.e. 160°, 150° and 140°C. The hollows of the plastic jacket pipe caused by the compressive strains are registered by displacement transducers (see Figure 7-7).

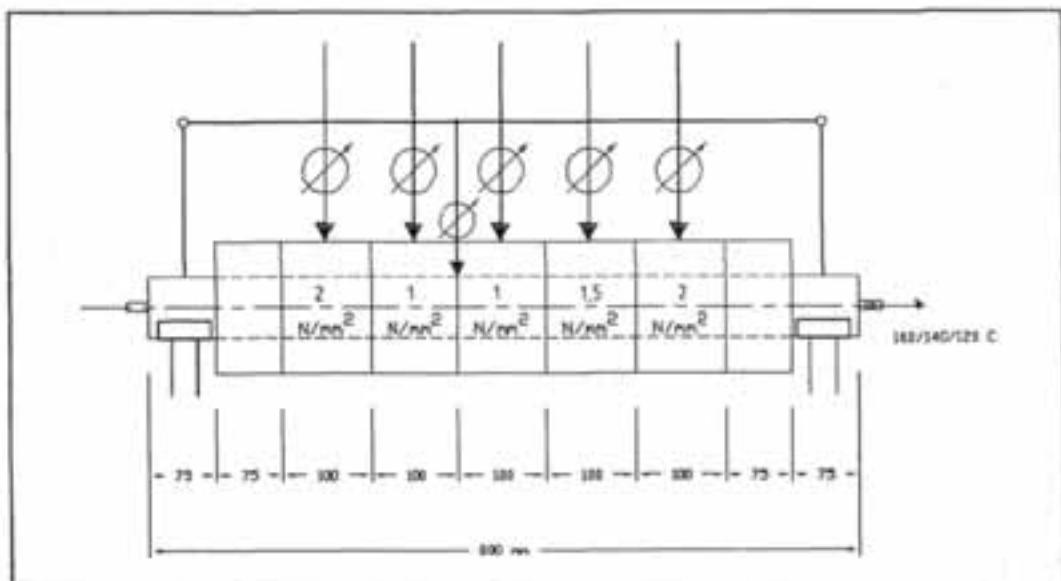


Figure 7-7: Procedure dealing with test pipes

The tests were planned by GEF, Leimen, and carried through at RWTÜV in Essen/Germany. Here, an interesting comparison with radial compression strength of non-reinforced plastic jacket pipes resulted, which were investigated in the project "Operational Self-Prestressing", carried through by Fernwärme Niederrhein GmbH, Dinslaken, Germany, took place.

Figure 7-8 shows the test bay. In the background, there are three plastic jackets reinforced with expanded glass beads; in the front the non-reinforced plastic jacket pipes can be seen.

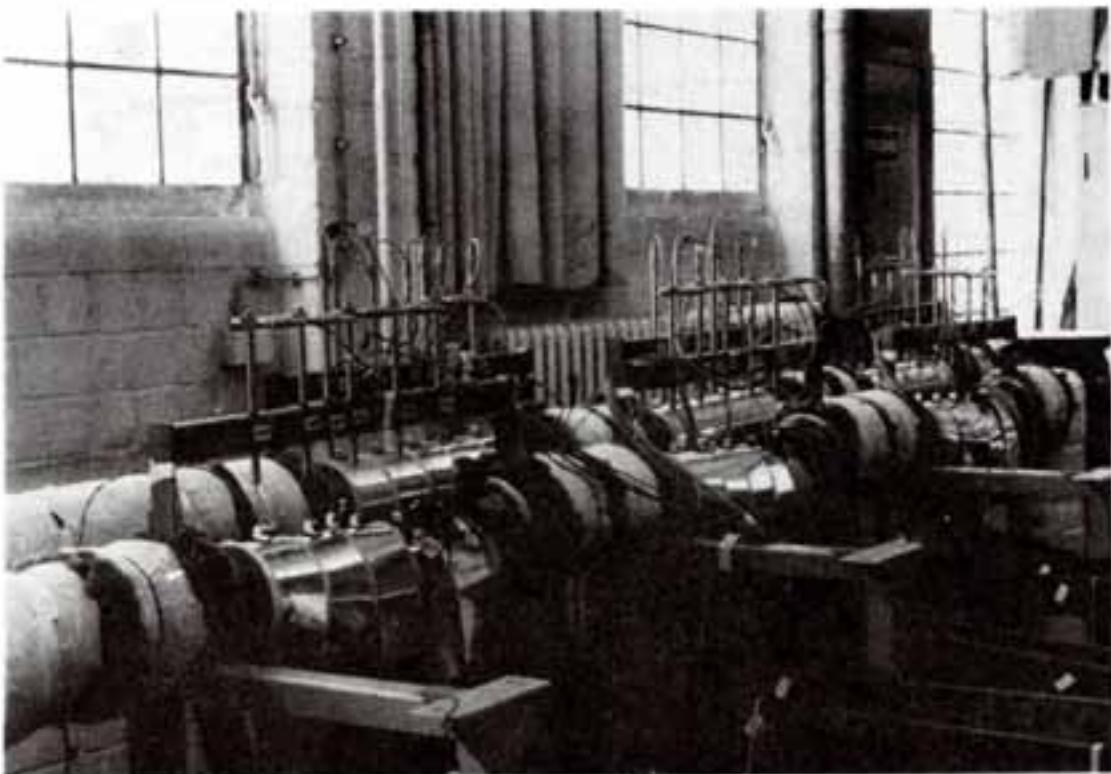


Figure 7-8: The test bay

## 8. Test Results

### 8.1 Short-Time Tests

#### 8.1.1. Compression Tests

Figures 8-1 to 8-4 show the load deflection curves which were recorded by the compression-tension-device. From each type of foam, three specimens were investigated under a speed of load application  $v = 10 \text{ mm/min}$  and an additional expanded glass foaming pipe without CFC with  $v = 5 \text{ mm/min}$ .

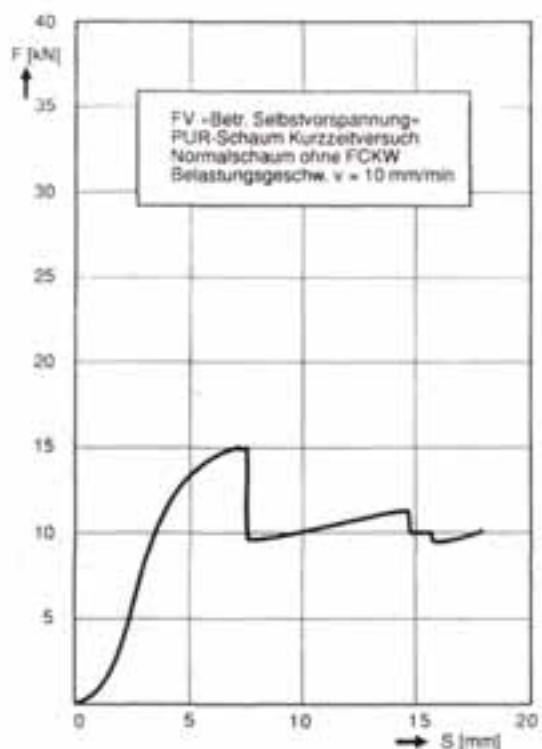


Figure 8-1: Force/displacement  
of normal foam  
without CFC

Figure 8-2: Force/displacement  
of normal foam  
with CFC

For all pipes - disregarding if they are normal pipes or expanded glass foam pipes, the curves are first rising to an e-function, then they drop.

The decrease of the force is caused by pulling-off off the foam at the lower side of the service pipe, where it is not compressed but subjected to tension. The decrease indicates the change in adhesion to the steel pipe for the unaged foam under room temperature.

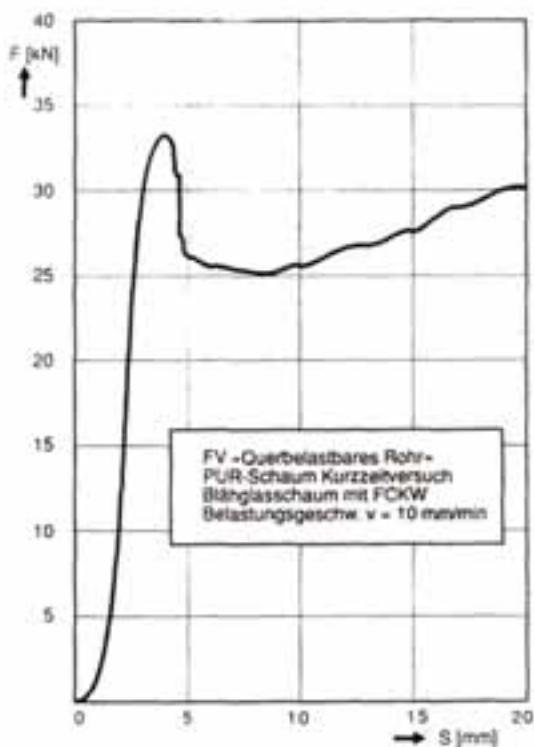
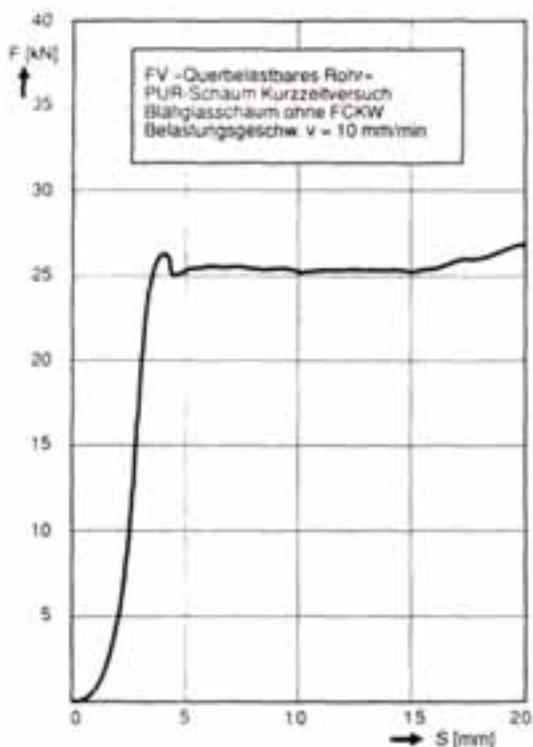


Figure 8-3: Force VS  
displacement of  
expanded glass  
foam without CFC

Figure 8-4: Force VS  
displacement of  
expanded glass  
foam with CFC

Regarding normal foam (see Figure 8-1 and 8-2), the first dropping of the force is followed by further sudden dropings. In case of normal foam without CFC, there were 2 sudden dropings, in case of normal foam with CFC, more than 2.

These force-droppings result from the cracks which are forming at the 2 and 10 o'clock positions of the foam.

For expanded glass foam, the first force-dropping is not as steep as for normal foam (Figure 8-3 and 8-4). Besides, no further force droppings take place. After the first dropping, the course indicating the force is almost constantly horizontal.

Considering the tests presented here, the following statements may be made regarding the short-time compression resistance under room temperature:

- Normal foam: without CFC bigger than with CPC
- Expanded glass foam: without CFC smaller than with CFC
- Speed of load application 10 mm/min or 5 mm/min does not show any difference regarding the value of the short-time compression resistance.

#### 8.1.2 Thermo Mechanical Analysis (TMA)

After the softening of CO<sub>2</sub> foam was found out on occasion of the first creep-rupture-compression tests, TMA-measurements were carried out at all specimens which had been left over for this purpose. The TMA-curves of the pipes with CO<sub>2</sub> foam are presented in Appendix 1, those of the CFC pipes are presented

in Appendix 2. The CO<sub>2</sub> foam already starts softening with 90 °C, whereas CFC foam only starts softening with 170 °C.

Each 5th TMA was carried through on foam between expanded glass beads. The increased value is due to the foam's increased density, since - inspite of the beads filling - about the same amount of foam has to be filled in because of the beads' high surface activity.

#### 8.2. Radial Creep Rupture Compression Tests

Appendix 3 shows the systematic for the presentation of the results, for the example of the 160 °C test. The results for the normal foam with CFC-11 under different temperatures are shown in Figure 8-5. Figure 8-6 shows the results obtained for the transverse loadable foam with CFC-11. Although the load on the bends for plastic jacket pipe able to withstand high transverse loadings was 5 to 20 times higher than those for normal foam pipes, the foam's deformations were only 20 to 50% compared to normal foam.

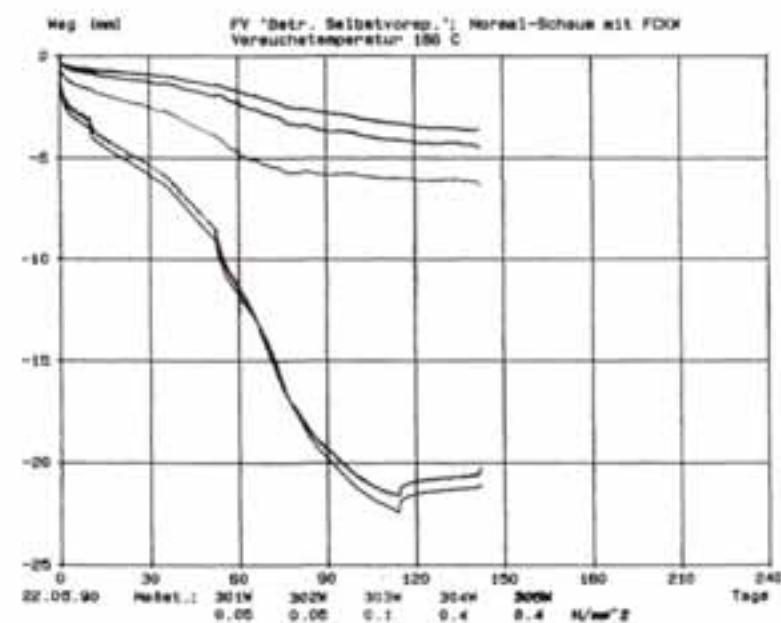
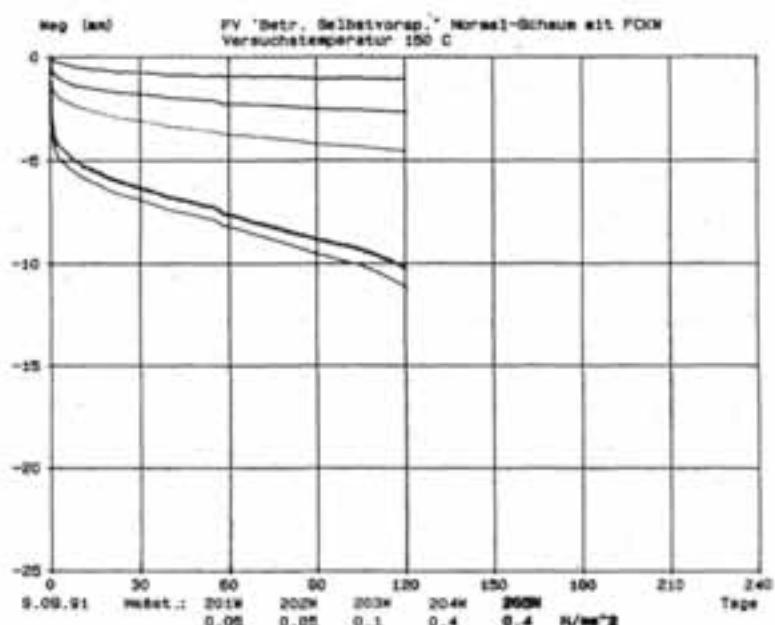
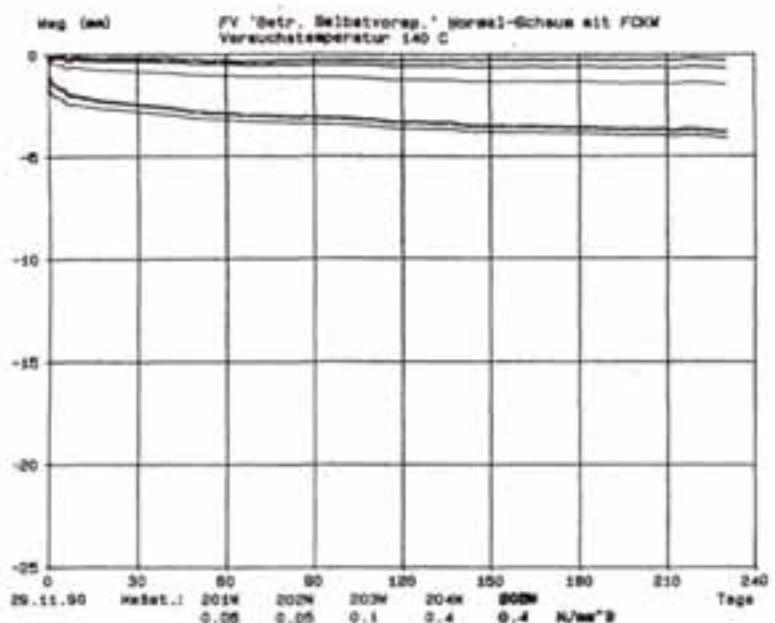


Figure 8-5: Heat marks at normal foam pipes with CFC-11 under different temperatures.

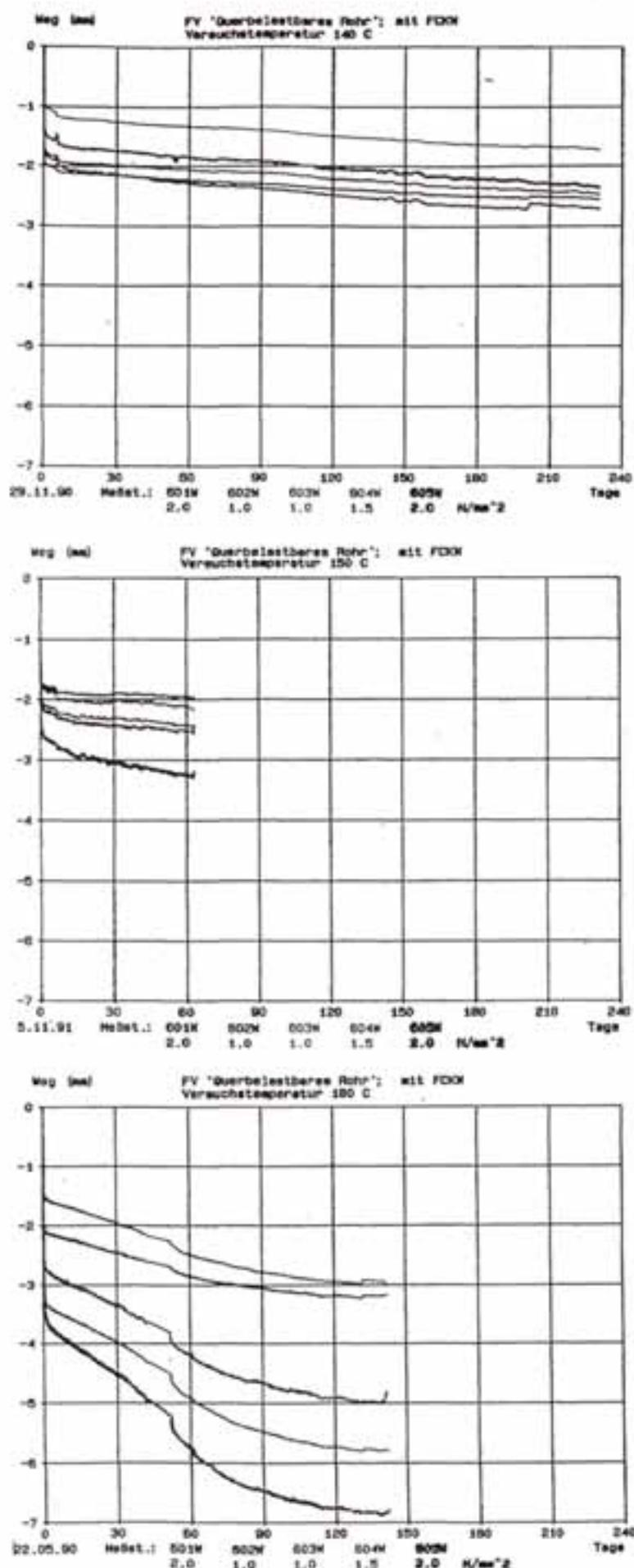


Figure 8-6: Heat marks at transverse loadable pipes with CFC-11

After the occurring of short initial heat marks, The bends for plastic jacket pipe able to withstand high transverse loadings shows a stable load carrying behaviour which is almost independent from time and ageing. Even under maximum load of 2 N/mm<sup>2</sup>, the insulation suffers an average of only 7 mm, which is tolerable.

It can definitely be stated that the transverse loadable foam is able to bear loads which - even under the influence of temperature, load and time - are at least 10 times higher than those of normal, non-reinforced PUR foam.

The permissible radial compressive strain of the transverse loadable foam is at least

all SIGPUR = 1.0 MPa

Results for the CO<sub>2</sub> foams show that in 1989 no good substitute had been found for CFC-11.

9. Possibilities of Application for Bends for Plastic Jacket Pipes able to withstand high Transverse Loadings; Cost Saving Potentials

If the remaining tests should confirm the positive results obtained so far by applying the new bends for plastic jacket pipe systems able to withstand high transverse loadings, the route planning could be simplified at a large extent, because this would be a simple method for angular deviations of the fine routing between 0° and 90° without compensation elements. The increased flexibility in the line routing offers a high cost saving potential in certain cases.

Regarding the costs, another advantage would be that the permissible laying lengths of cold laid pipe lines would not be limited by the maximum expansions which can be taken up by expansion pads. This would be important also for other development strategies (especially for the application of cold laying) giving a high cost saving potential.

There is another most important factor in relation to this new development, i.e. that with the expansion pads an important weak point of the plastic jacket pipe system can be eliminated which undoubtedly is very useful for a long-term application.

## 10. Examples for Realization

In 1992, the first service pipes were constructed using bends able to withstand high transverse loadings. A systematic testing under operational conditions is carried out at various lines, with pipe diameters between DN 40 and DN 150. These tests are carried out by GEW in Cologne (see Figures 10-1 and 10-2).

Trasse 1 = Teil 1

M 1 : 1000 (nach Vergrößerung auf DIN-A3)

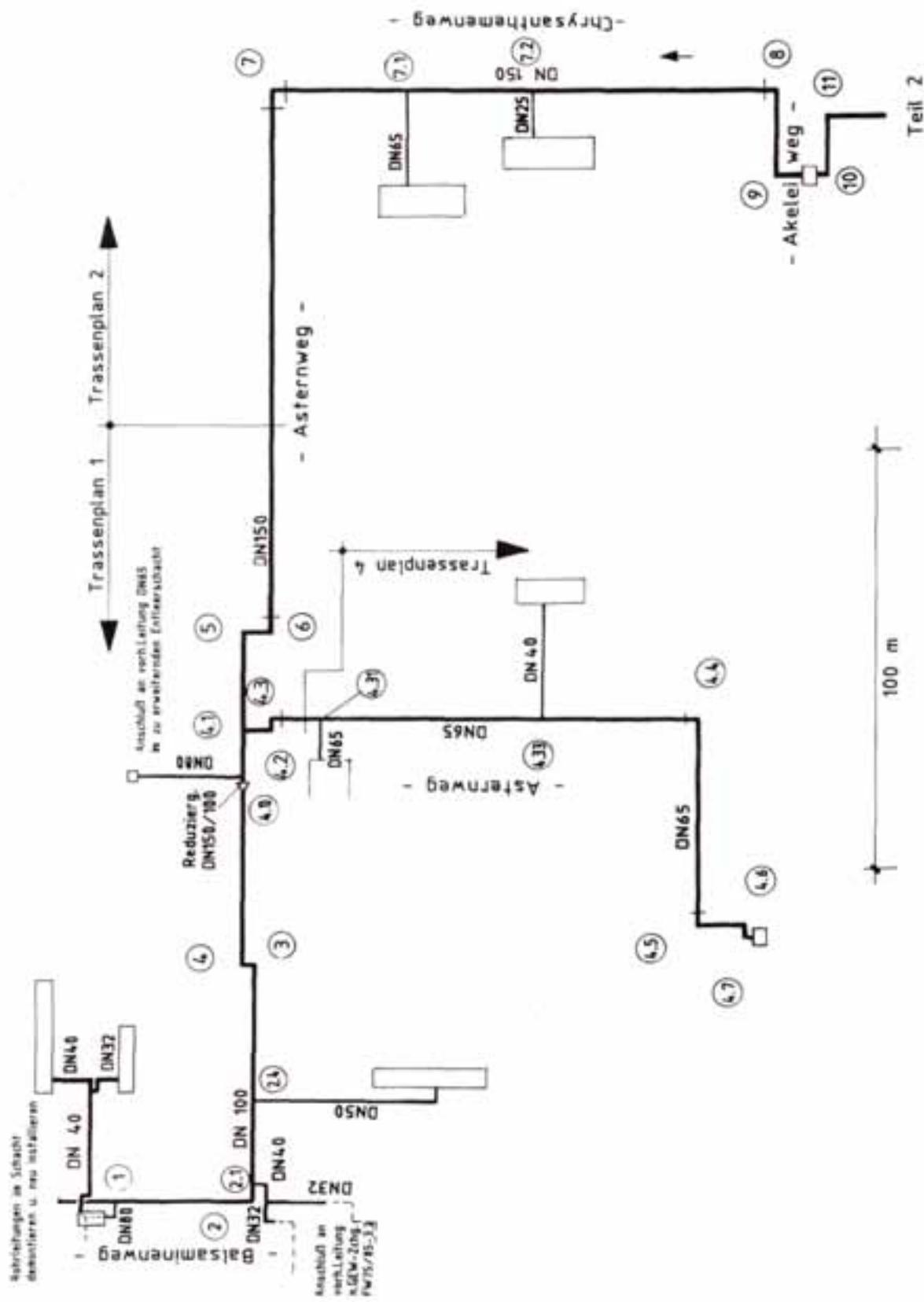


Figure 10-1: Sketch of the line - part 1

Trasse 1 - Teil 2

M 1 : 1000 (nach Vergrößerung auf DIN-A3)

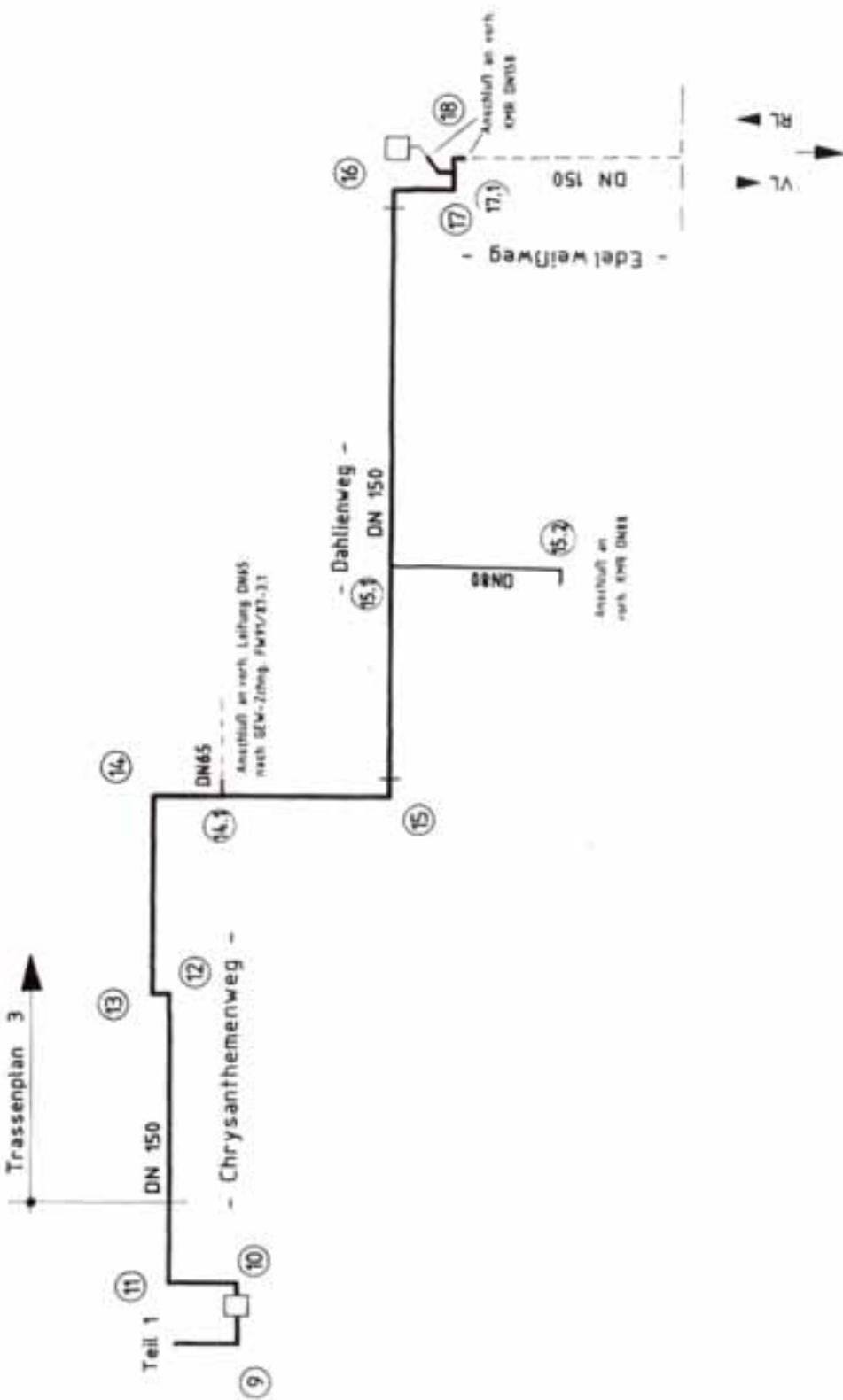


Figure 10-2: Sketch of the line - part 2

The dimensioning of the bends able to withstand high transverse loadings was carried out with the computer program system GEFKMR [2]. Figure 10-3 shows the chosen design for the operational conditions in Cologne (cold laying,  $T_{max} = 110^{\circ}\text{C}$ ).

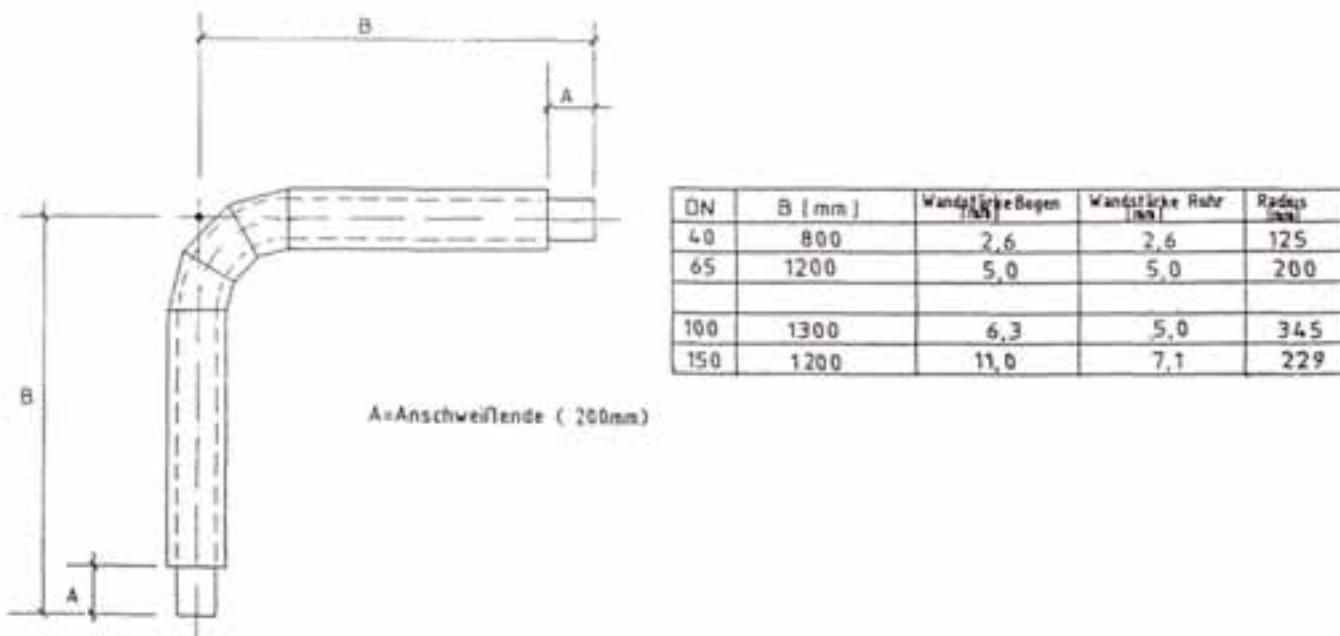


Figure 10-3: Required length for the bend, wall thicknesses and bend radius for the test tracks at Cologne.

In Appendix 4 a complete outprint of the calculation according to [2] is shown.

The calculation is checked by numerous measurements. All displacements were measured with the help of measurement T-pieces which were developed only for this purpose (see Figure 10-4).

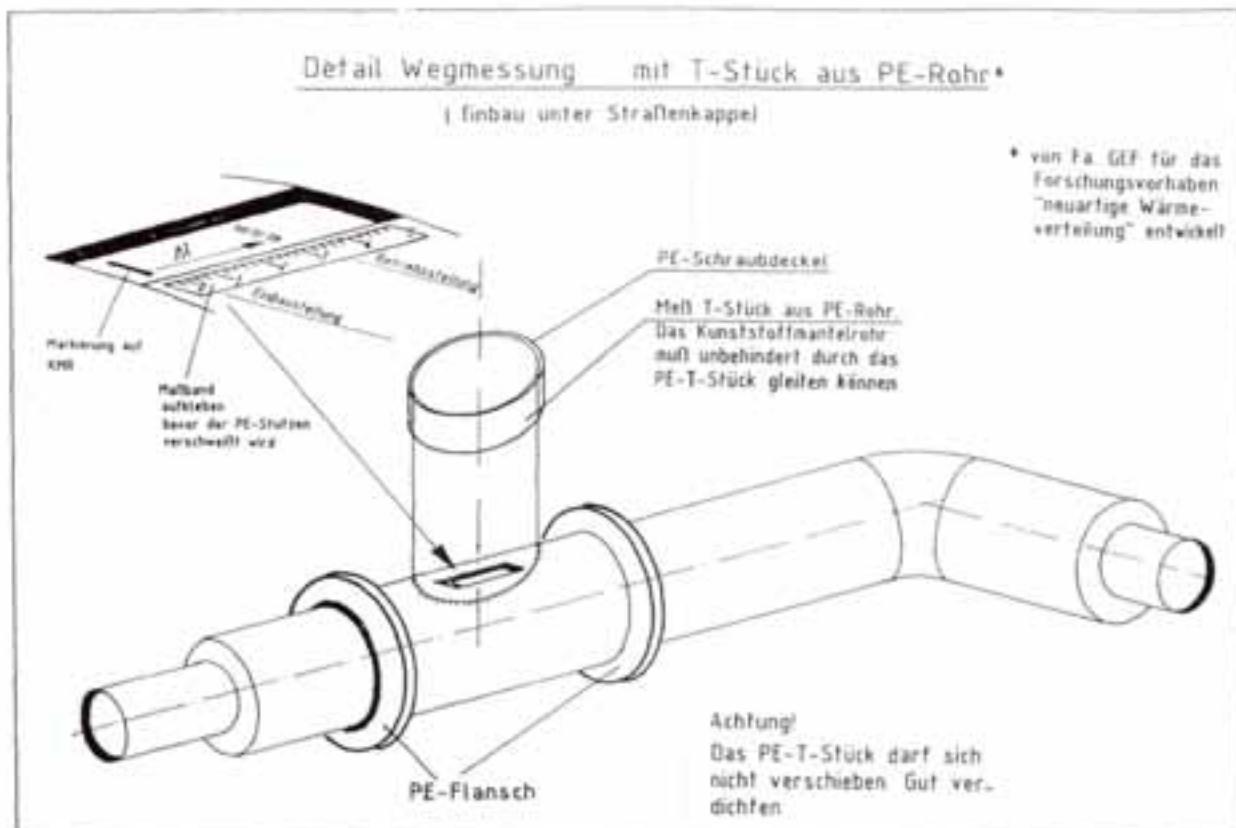


Figure 10-4: Displacement measurement with measurement T-piece

All expansions occurring in longitudinal and in circumferential direction at especially high loaded bends were measured at 40 circumferential points with the help of wire strain gauges and then compared to the values obtained with the calculation.

11. Literature

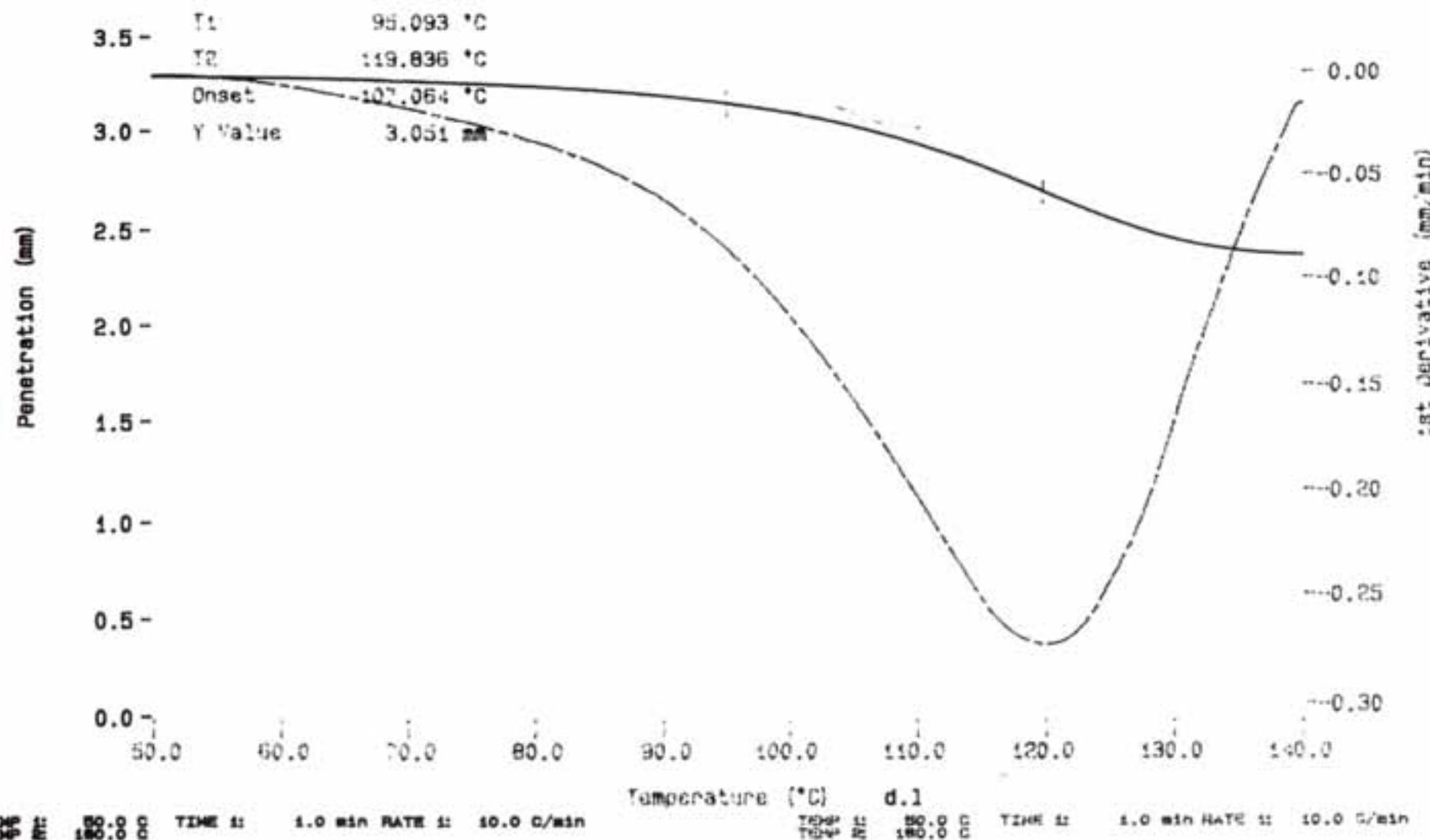
- [1] Audibert, J.M.E und Nyman, K.J.: Soil Restraint against horizontal Motion of Pipes  
Journal of the Geotechnical Engineering Disision,  
Oct. (1977)
  
- [2] GEFKMR: Programm zur Statischen Berechnung und Optimierung von Kunststoff-Mantelrohren.  
GEF Gesellschaft für EDV-Software mbH, Leimen  
(1986, 1992)

**APPENDIX 1**

TMA File Name: ts02  
Sample Height: 6.117 mm  
Thu Mar 08 17:39:16 1990  
part 1 of the pipe

PCMKII-DERIVED  
T Series Thermal Analysis System

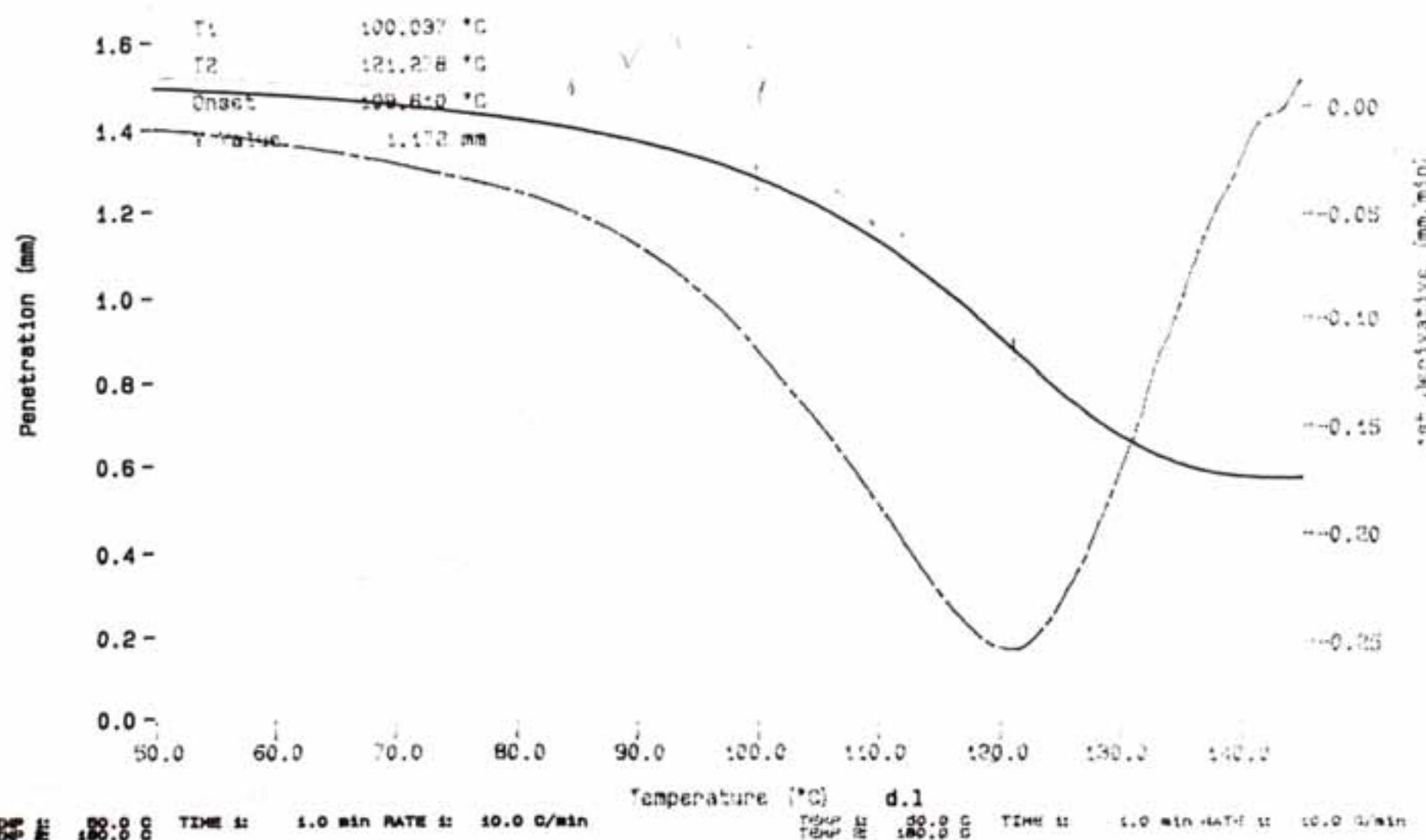
TMA 1st Derivative: ts02  
Sample Height: 6.117 mm  
Thu Mar 08 17:39:16 1990  
part 1 of the pipe



TMA File Name: ts06  
Sample Height: 6.232 mm  
Thu Mar 08 19:28:33 1990  
part 3 of the pipe

PENKEL-DUPONT  
T Series Thermal Analysis System

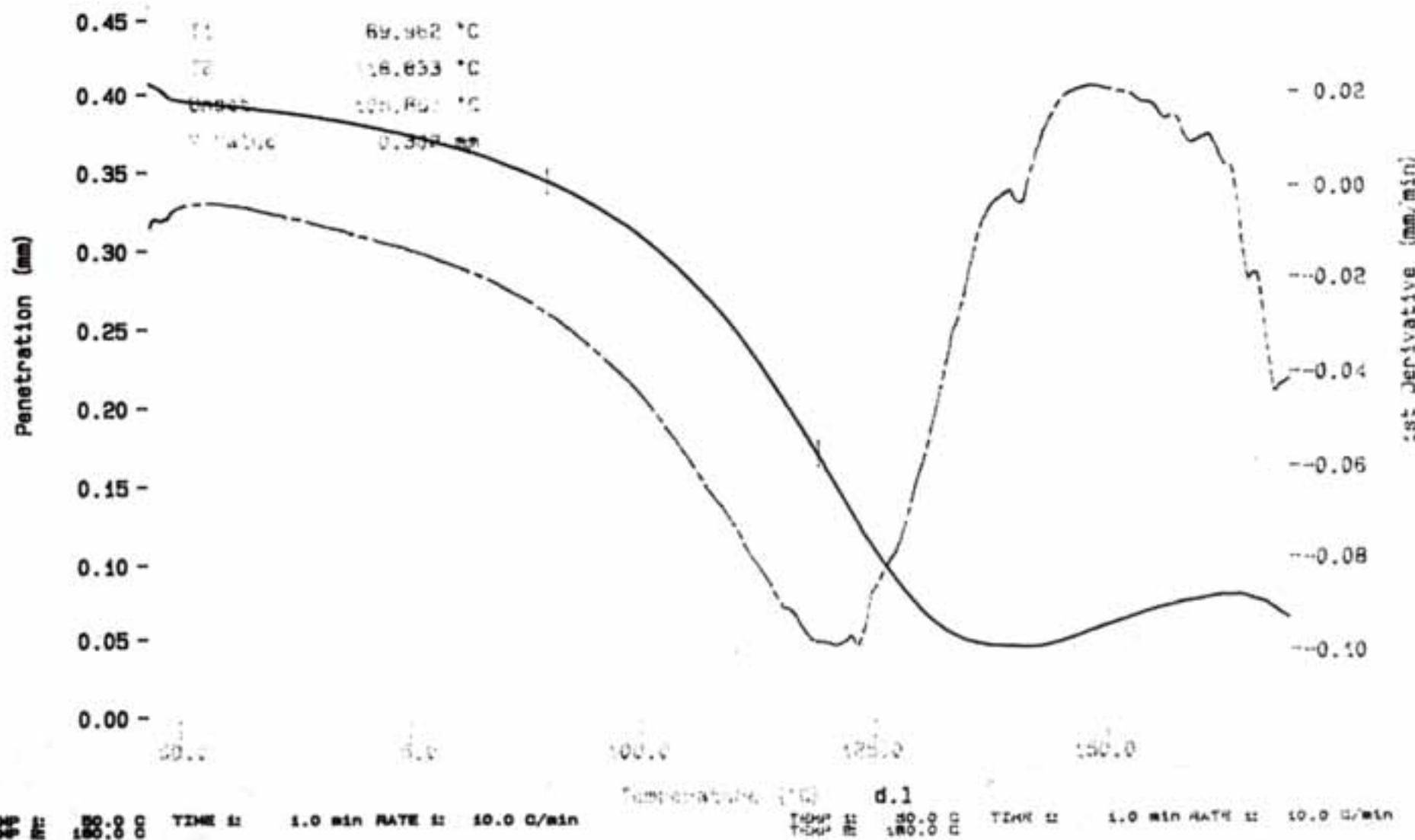
TMA test derivative: ts06  
Sample height: 6.232 mm  
Thu Mar 08 19:28:33 1990  
part 3 of the pipe



TMA File Name: tes07  
Sample Height: 7.638 mm  
Thu Mar 08 19:50:19 1990  
part 5 of the pipe

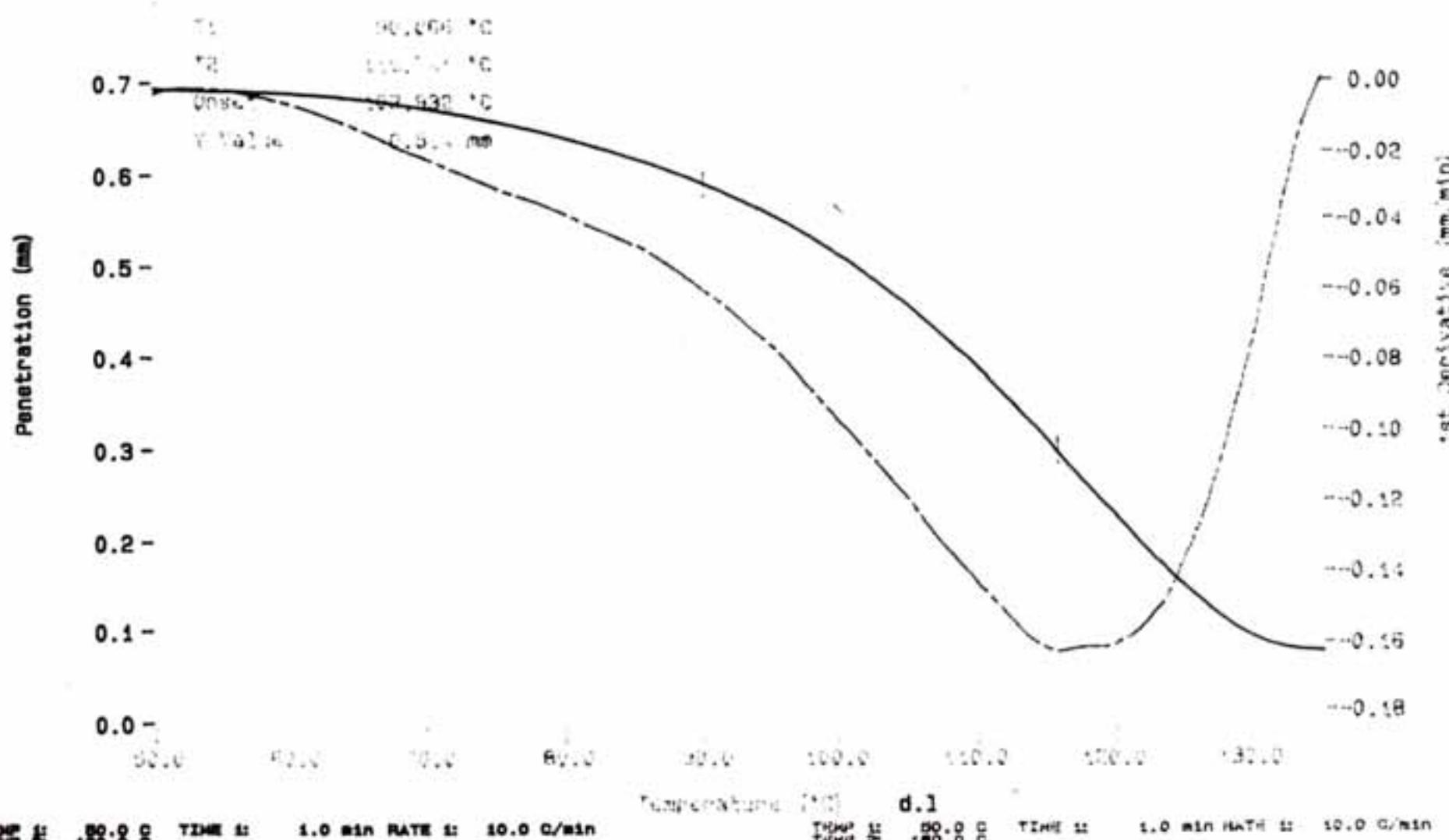
TA 2100 Series Thermal Analysis System

TMA 1st Derivative: tes07  
Sample Height: 7.638 mm  
Thu Mar 08 19:50:19 1990  
part 5 of the pipe



TMA File Name: ts08  
Sample Height: 7.299 mm  
Thu Mar 08 20:12:24 1990  
part 7 of the pipe

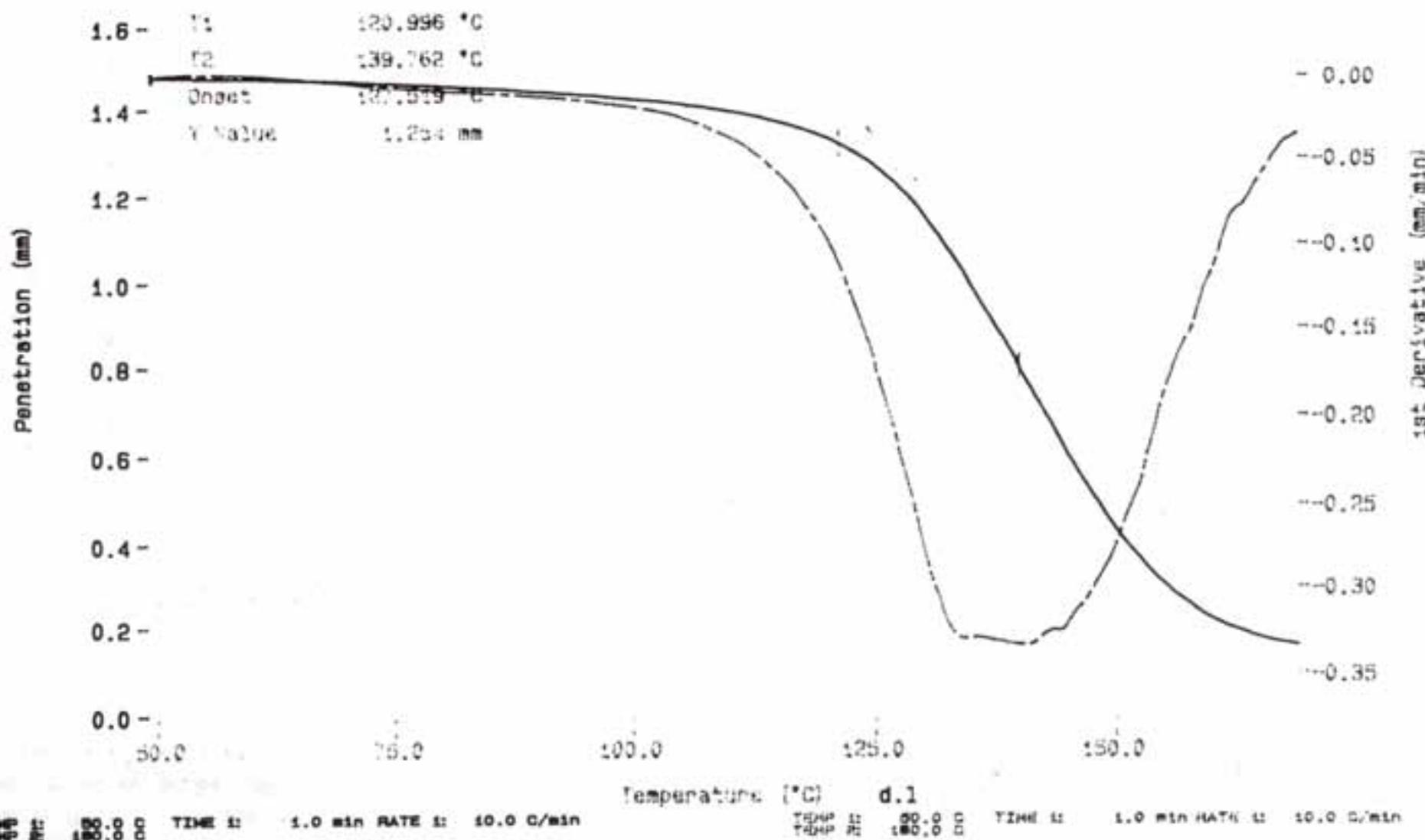
TMA 1st Derivative: ts08  
Sample Height: 7.299 mm  
Thu Mar 08 20:12:24 1990  
part 7 of the pipe



TMA File Name: ts05  
Sample Height: 6.101 mm  
Thu Mar 08 19:03:00 1990  
pipe with glass balls

PerkinElmer  
T Series Thermal Analysis System

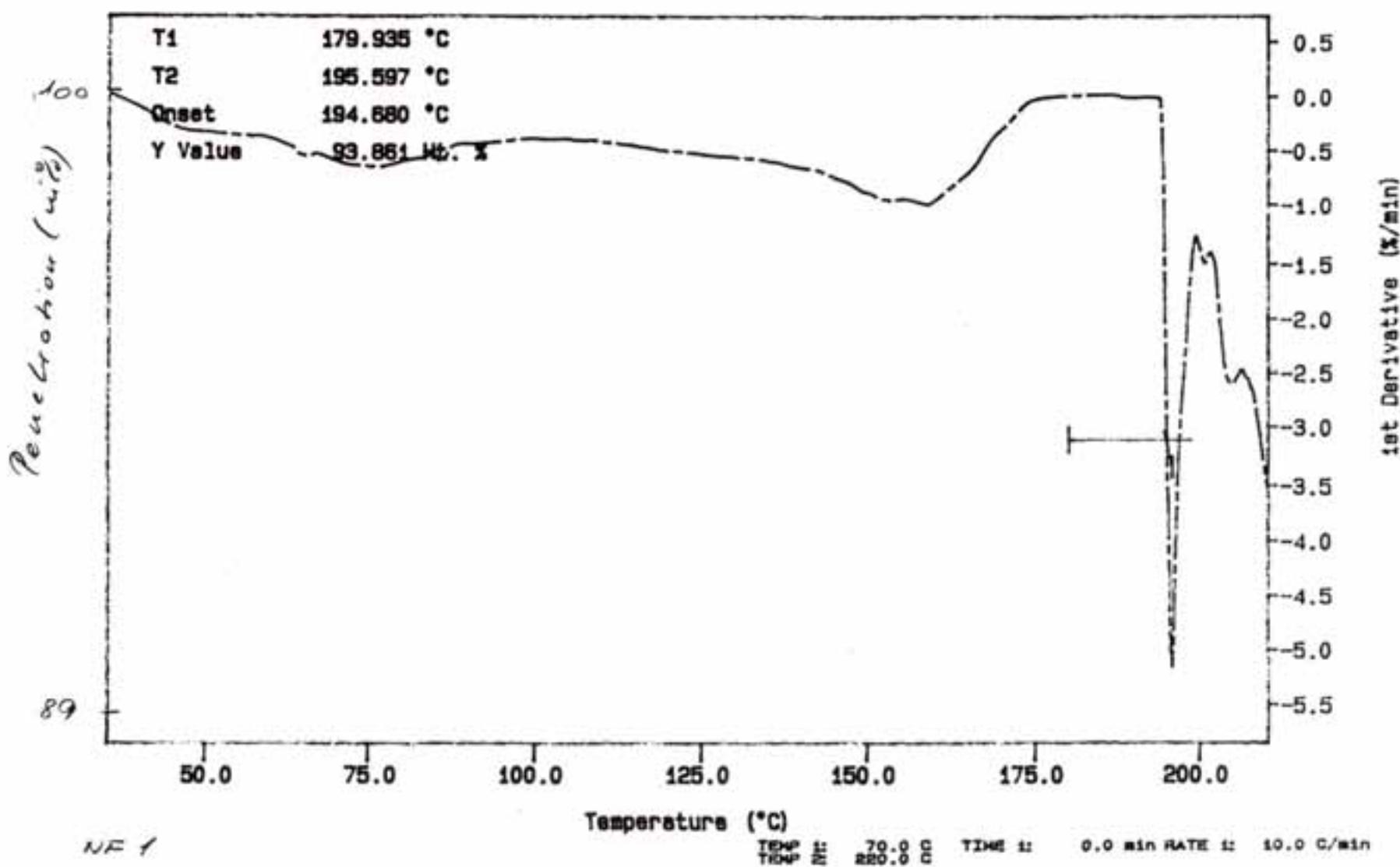
TMA 1st Derivative: ts05  
Sample Height: 6.101 mm  
Thu Mar 08 19:03:00 1990  
pipe with glass balls



**APPENDIX 2**

PERKIN-ELMER  
7 Series Thermal Analysis System

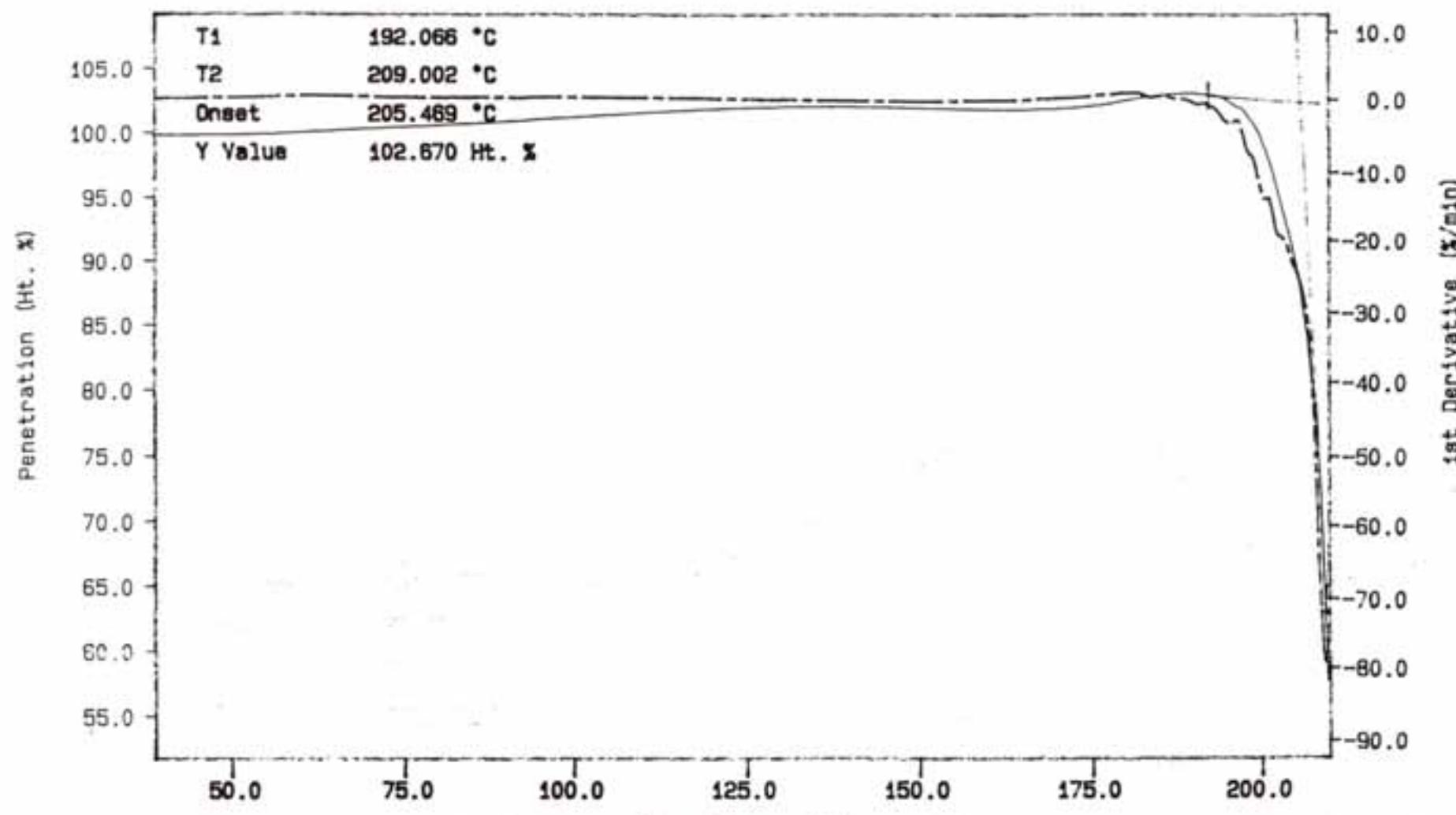
TMA 1st Derivative: tu3  
Sample Height: 7.247 mm  
Fri Jul 20 09:32:35 1990  
TUV pipes  
(Normalized)



TMA Normalization: tu4  
Sample Height: 7.703 mm  
Fri Jul 20 10:03:42 1990  
TUV pipes  
(Normalized)

PERKIN-ELMER  
7 Series Thermal Analysis System

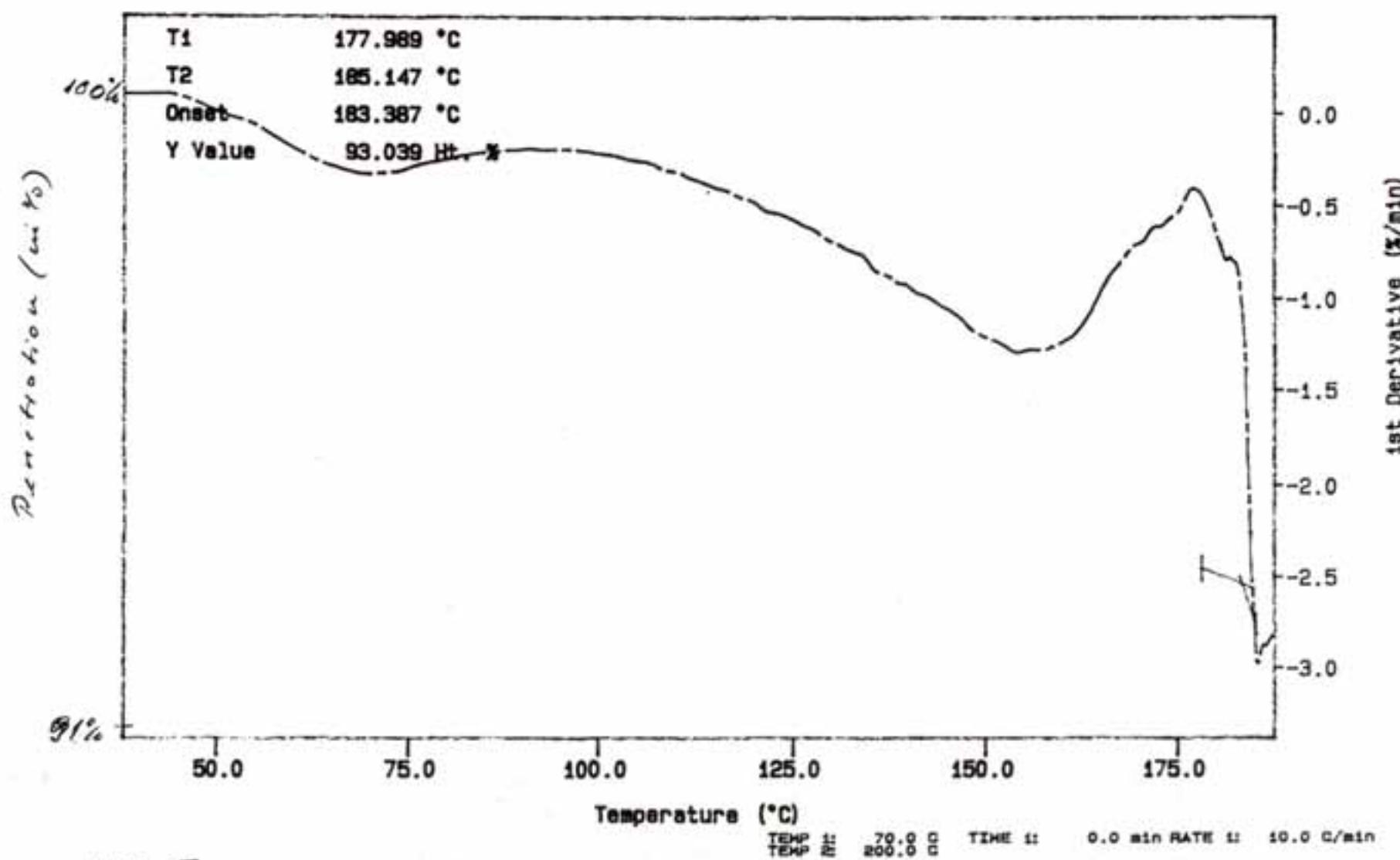
TMA 1st Derivative: tu4  
Sample Height: 7.703 mm  
Fri Jul 20 10:03:42 1990  
TUV pipes  
(Normalized)



NF3  
TEMP 1: 70.0 C TIME 1: 0.0 min RATE 1: 10.0 C/min  
TEMP 2: 220.0 C TIME 2: 0.0 min RATE 2: 10.0 C/min  
TEMP 3: 70.0 C TIME 3: 0.0 min RATE 3: 10.0 C/min  
TEMP 4: 220.0 C TIME 4: 0.0 min RATE 4: 10.0 C/min

PERKIN-ELMER  
7 Series Thermal Analysis System

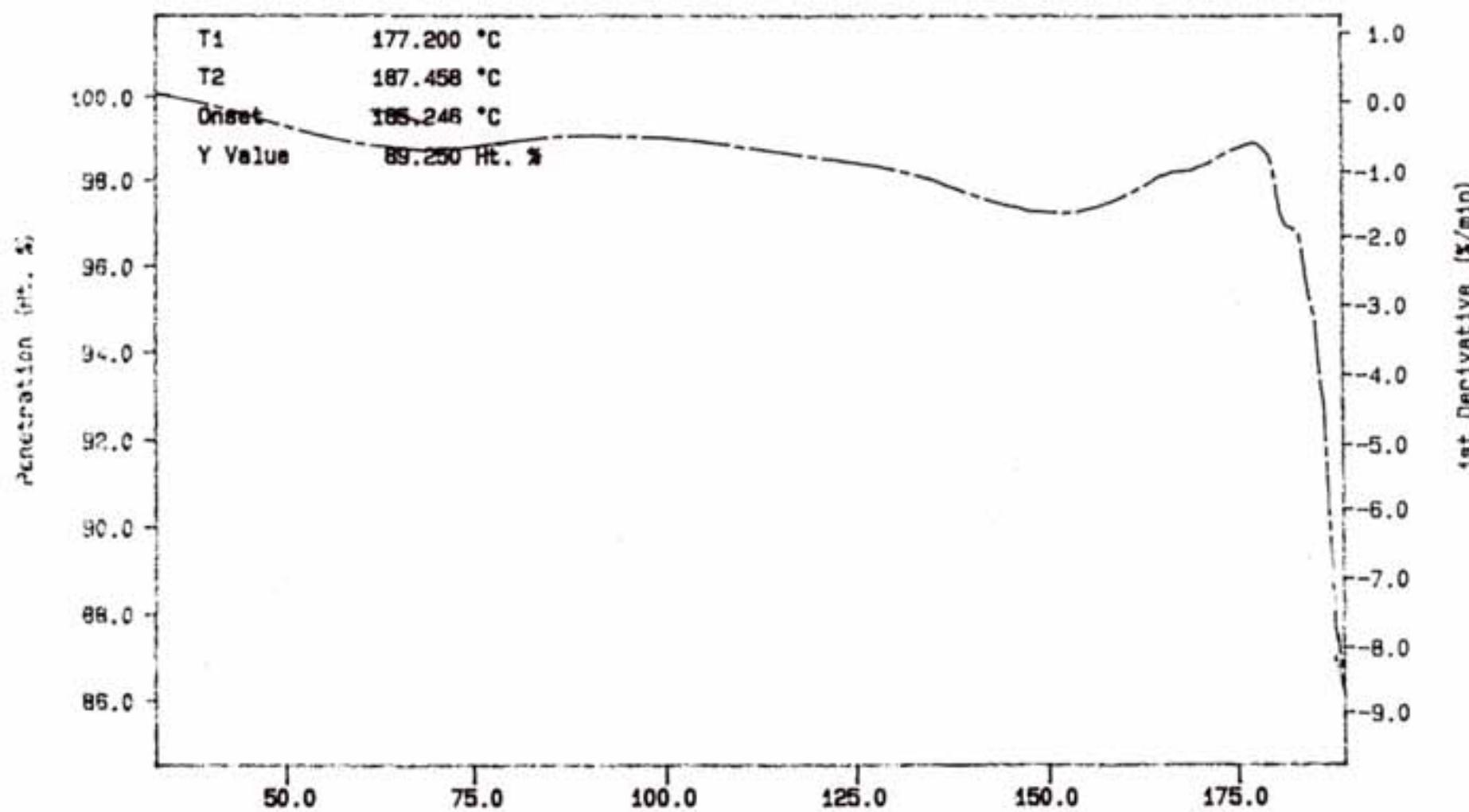
TMA 1st Derivative: tuvi  
Sample Height: 6.627 mm  
Thu Jul 19 11:45:20 1990  
TUV PIPES  
(Normalized)



File Normalization: pp12  
Sample Height: 6.684 mm  
Thu Jul 19 09:27:36 1990  
TUV PIPES  
(Normalized)

PERKIN-ELMER  
7 Series Thermal Analysis System

TMA 1st Derivative: pp12  
Sample Height: 6.684 mm  
Thu Jul 19 09:27:36 1990  
TUV PIPES  
(Normalized)



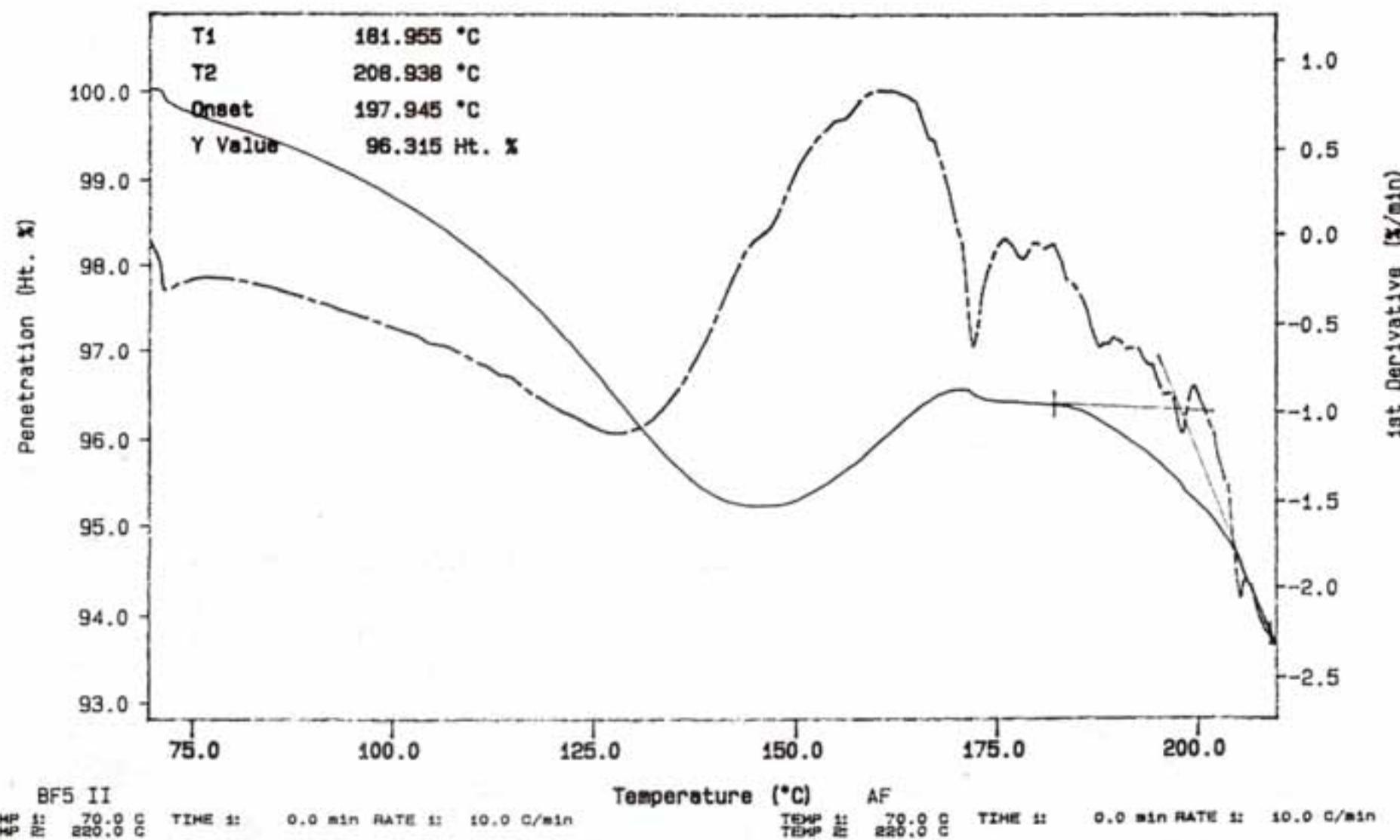
sample: T-NF 7  
TEMP I: 70.0 C TIME I: 0.0 min RATE I: 10.0 C/min  
TEMP R: 200.0 C

Temperature (°C) AF  
TEMP I: 70.0 C TIME I: 0.0 min RATE I: 10.0 C/min  
TEMP R: 200.0 C

TMA Normalization: tu6  
Sample Height: 7.108 mm  
Fri Jul 20 11:00:02 1990  
TUV pipes  
(Normalized)

PERKIN-ELMER  
7 Series Thermal Analysis System

TMA 1st Derivative: tu6  
Sample Height: 7.108 mm  
Fri Jul 20 11:00:02 1990  
TUV pipes  
(Normalized)



**APPENDIX 3**

# KUNSTSTOFF MANTELROHRE FÜR DIE FERNWÄRME

## RADIALE ZEITSTAND-DRUCKVERSUCHE

Die Forschungsvorhaben des AGFW-Verbundprojektes  
Neuartige Wärmeverteilung  
"Betriebliche Selbstvorspannung/Unterverteilung" und  
"Neue Prüftechniken und Systemkomponenten  
beim Kunststoff-Mantelrohr"



AGFW-VERBUNDPROJEKT  
NEUARTIGE WÄRMEVERTEILUNG

# NEUARTIGE WÄRMEVERTEILUNG: KUNSTSTOFF MANTELROHRE FÜR DIE FERNWÄRME



## BETRIEBLICHE SELBST-VORSPANNUNG BEI KUNSTSTOFF-MANTELROHREN

Wenn eine kaltverlegte Leitung zum ersten Mal die maximale Betriebstemperatur erreicht, treten an den Leitungsenden große Dehnwege auf, die je nach den Randbedingungen ungefähr 3 bis 4 mal so groß wie die entsprechenden Dehnwege vorgewärmter Leitungen sind.

## RADIALE DRUCKBELASTUNG

Von vornherein war klar, daß die Ringbiegebeanspruchung des Stahlrohres durch eine Erhöhung der Wanddicke verringert werden kann. Dagegen stellt die radiale Druckbeanspruchung des PUR-Schaumes das Hauptproblem dar. Die Dehnpolsterdicke kann kaum weiter erhöht werden, weil damit die Mantelrohrtemperatur weiter ansteigt und dickere Dehnpolster auch durch den Erddruck stärker komprimiert werden.

Die Grundlage für weitere Überlegungen bildet die Untersuchung der Druckfestigkeit des PUR-Schaumes unter praxisnahen Bedingungen.

Die zulässige radiale Druckbelastung von Kunststoff-Mantelrohren bei den üblichen maximalen Mediumtemperaturen zwischen 130 °C und 140 °C ist bisher nicht untersucht worden.

## ZEITSTAND-DRUCKVERSUCHE

Erstmals wurden in den Forschungsvorhaben "Betriebliche Selbstvorspannung/Unterverteilung" der FernwärmeverSORGUNG Niederrhein GmbH und "Neue Prüftechniken und Systemkomponenten beim Kunststoffmantelrohr" der Gas-, Elektrizitäts- und Wasserwerke Köln AG Kunststoff-Mantelrohre radialen Zeitstand-Druckversuchen unterzogen, bei denen die tat-

sächlich auftretenden Belastungen bei erhöhten Temperaturen aufgebracht werden, um einen Zeitraffereffekt zu erzielen. Dabei wurden 80 cm lange gerade Rohrabschnitte DN 80 am Mediumrohr aufgelagert und in fünf Prüfabschnitte unterteilt. Auf die Prüfabschnitte wurden radiale Druckspannungen aufgebracht, die Rückstellkräfte von weichen Dehnpolstermaterialien bis zur zweifachen maximalen Erdreichreaktion abdecken.

Die von der GEF, Leimen, geplanten Versuche wurden beim RWTÜV in Essen durchgeführt. Es wurde PUR-Normalschaum, FCKW-freier Normalschaum (Stand 1989), höherfester Schaum und höherfester FCKW-freier Schaum (Stand 1989) untersucht.

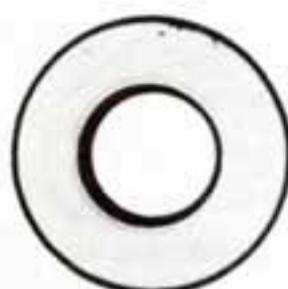
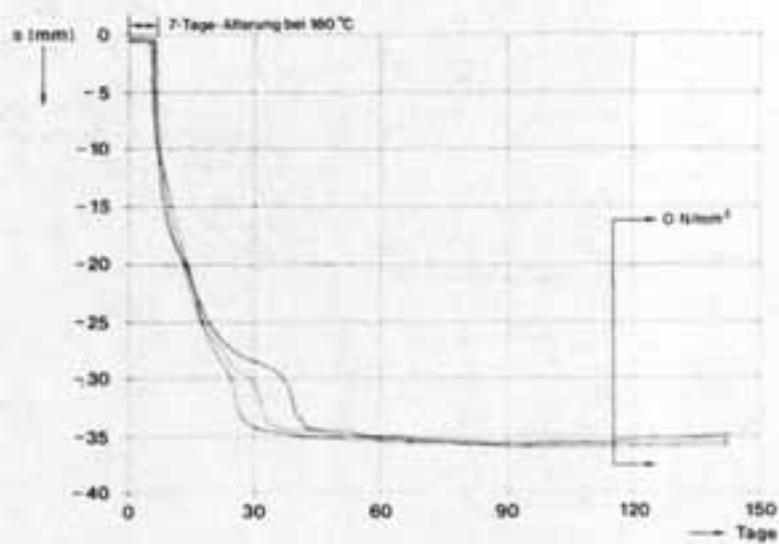
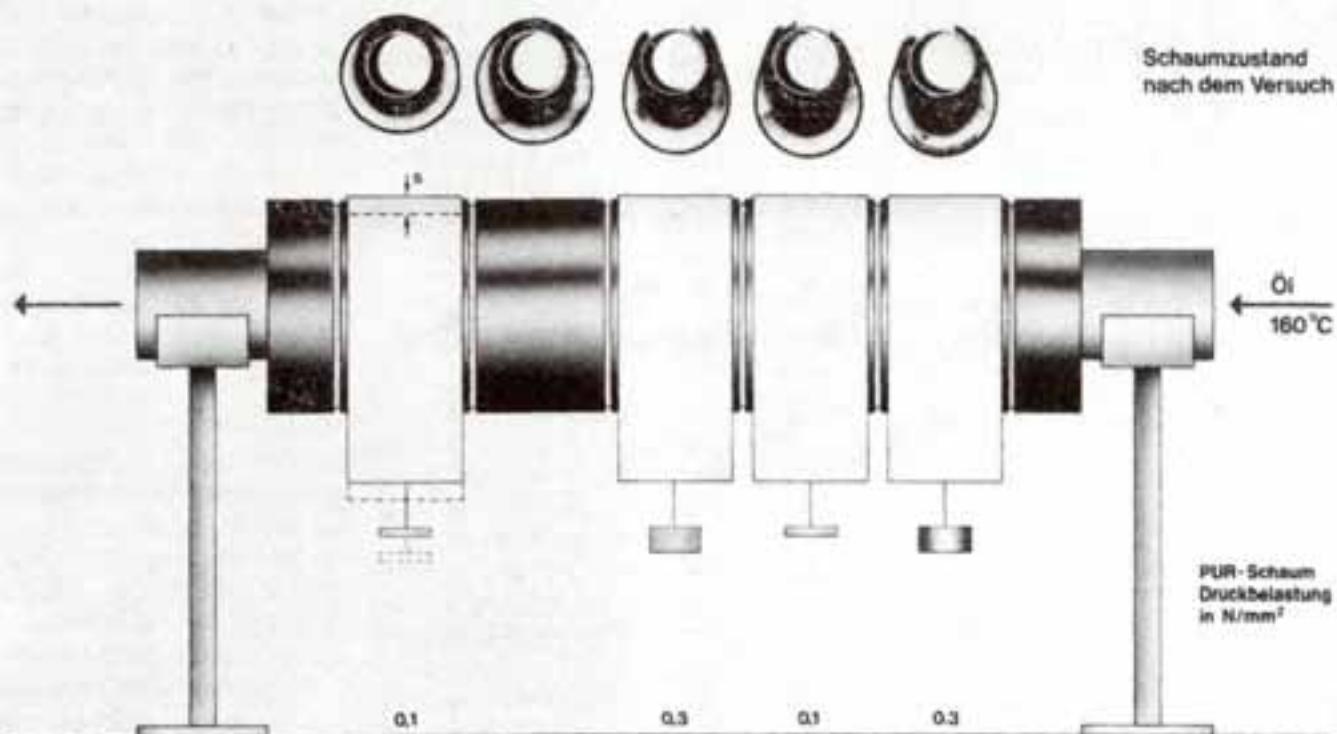
Die Ergebnisse der 160°C-Versuche und die Zwischenergebnisse der 140°C-Versuche sind in den folgenden Abbildungen dargestellt.

Eine Zwischenbewertung zeigt, daß die radiale Druckfestigkeit des FCKW-freien Schaumes (Stand 1989) beiden untersuchten Temperaturen wesentlich unter den Werten des Normalschaumes liegt. Die unterschiedlichen FCKW-freien Schäume sind deshalb für den Fernwärmeeinsatz nicht geeignet. Die Druckfestigkeit des höherfesten Schaumes liegt etwa um den Faktor 5–10 über der des PUR-Normalschaumes.

Eine abschließende Bewertung kann erst vorgenommen werden, wenn weitere Versuchsergebnisse vorliegen.

# RADIALE ZEITSTAND-DRUCKVERSUCHE VON KUNSTSTOFF-MANTELROHREN

Normalschaum ohne FCKW \*)



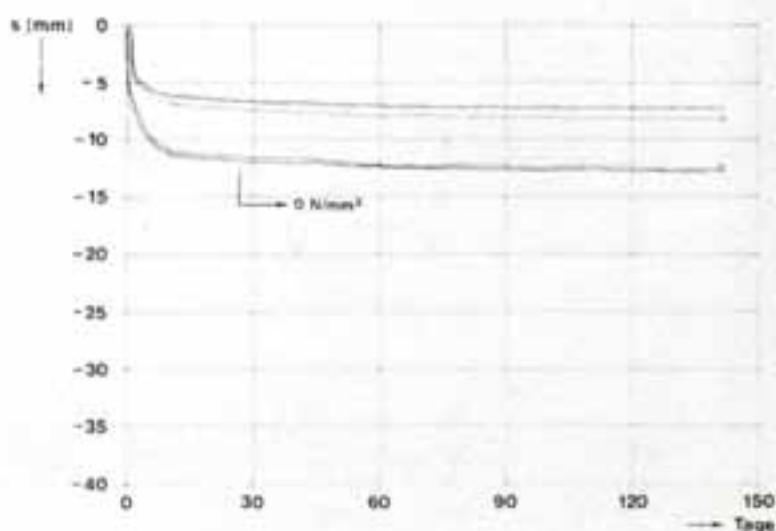
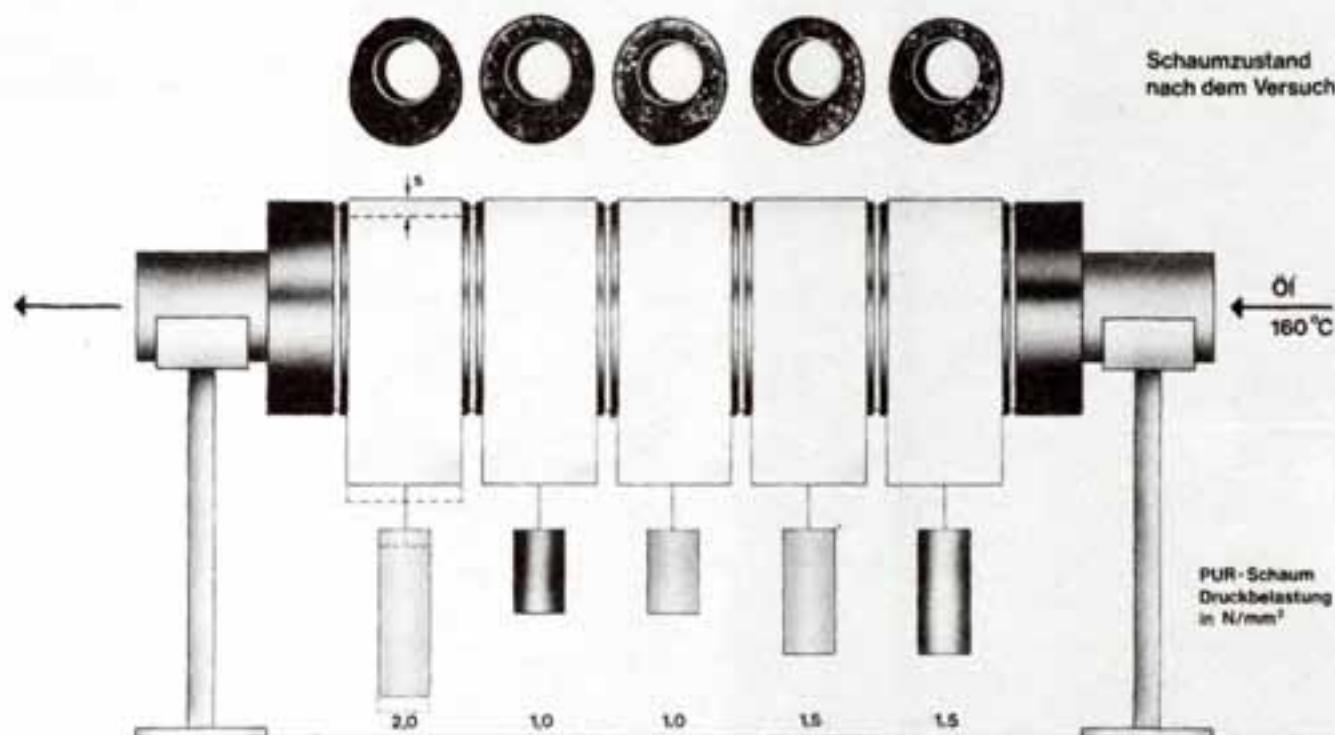
Schaumzustand  
vor dem Versuch  
\*) Entwicklungsstand  
Ende 1989



ERSTE ZWISCHENERGEBNISSE  
BEI 160° CELSIUS

# RADIALE ZEITSTAND-DRUCKVERSUCHE VON KUNSTSTOFF-MANTELROHREN

Querbelastbares Rohr ohne FCKW \*)



Schaumzustand vor dem Versuch

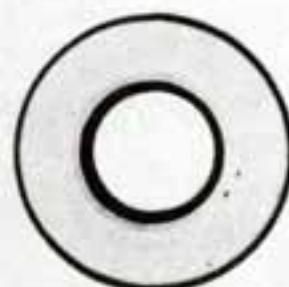
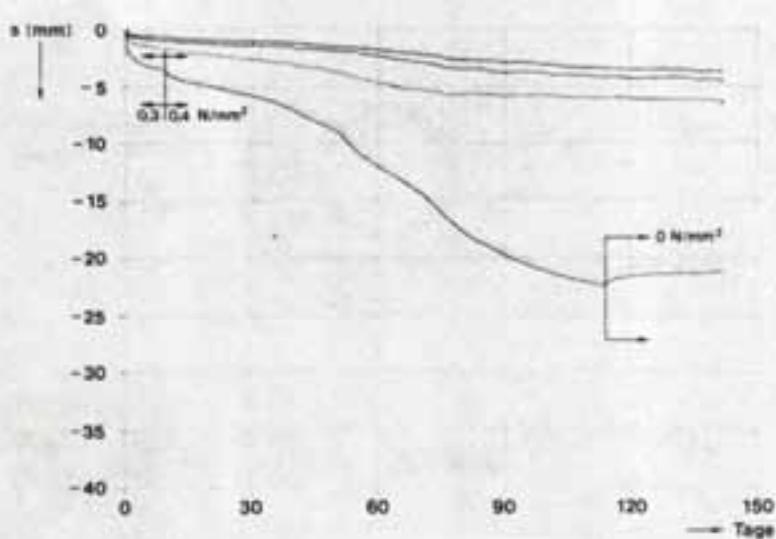
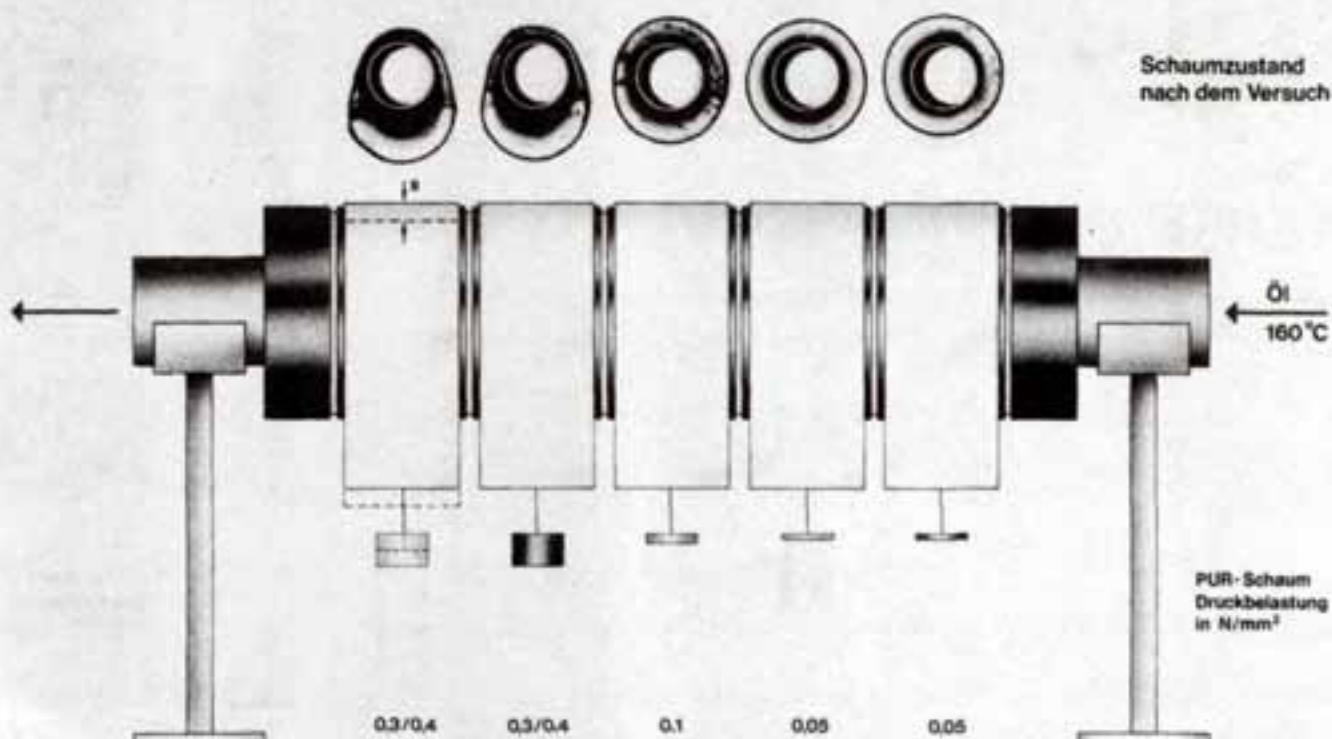
\*) Entwicklungsstand Ende 1989



ERSTE ZWISCHENERGEBNISSE  
BEI 160° CELSIUS

# RADIALE ZEITSTAND-DRUCKVERSUCHE VON KUNSTSTOFF-MANTELROHREN

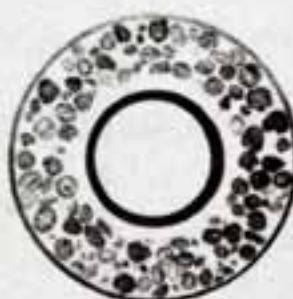
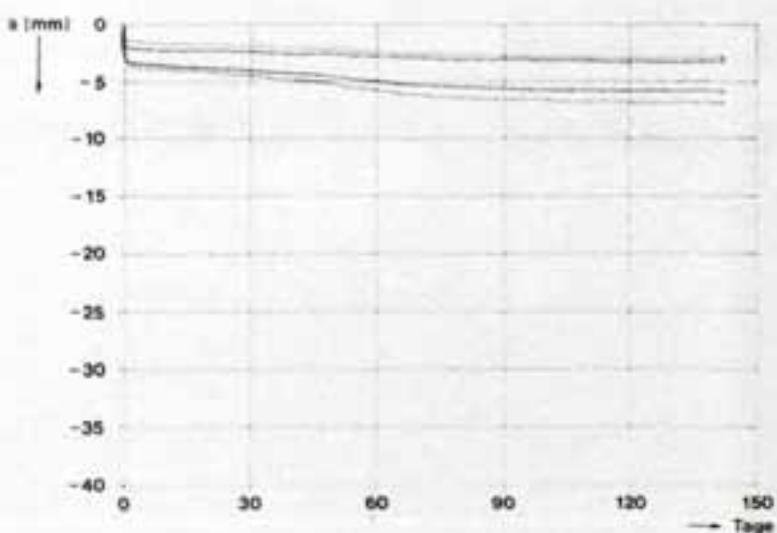
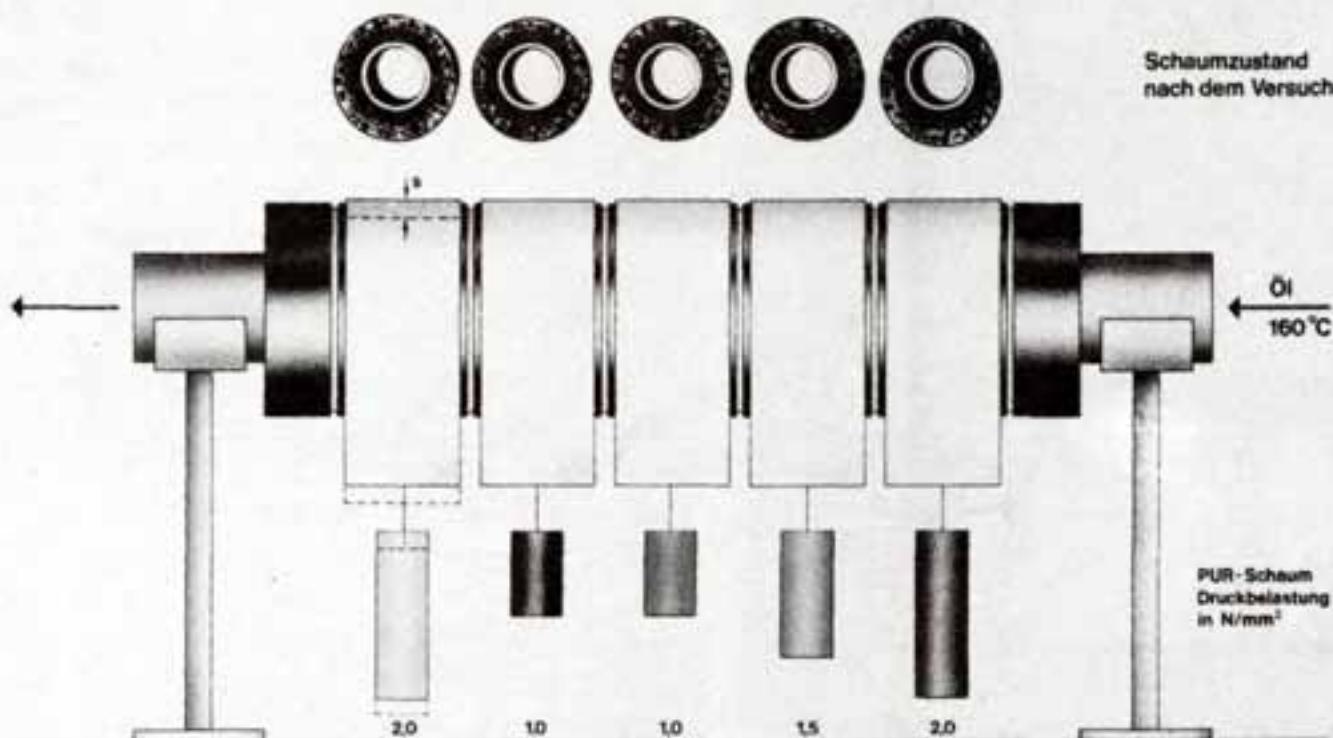
Normalschaum mit FCKW



ERSTE ZWISCHENERGEBNISSE  
BEI 160° CELSIUS

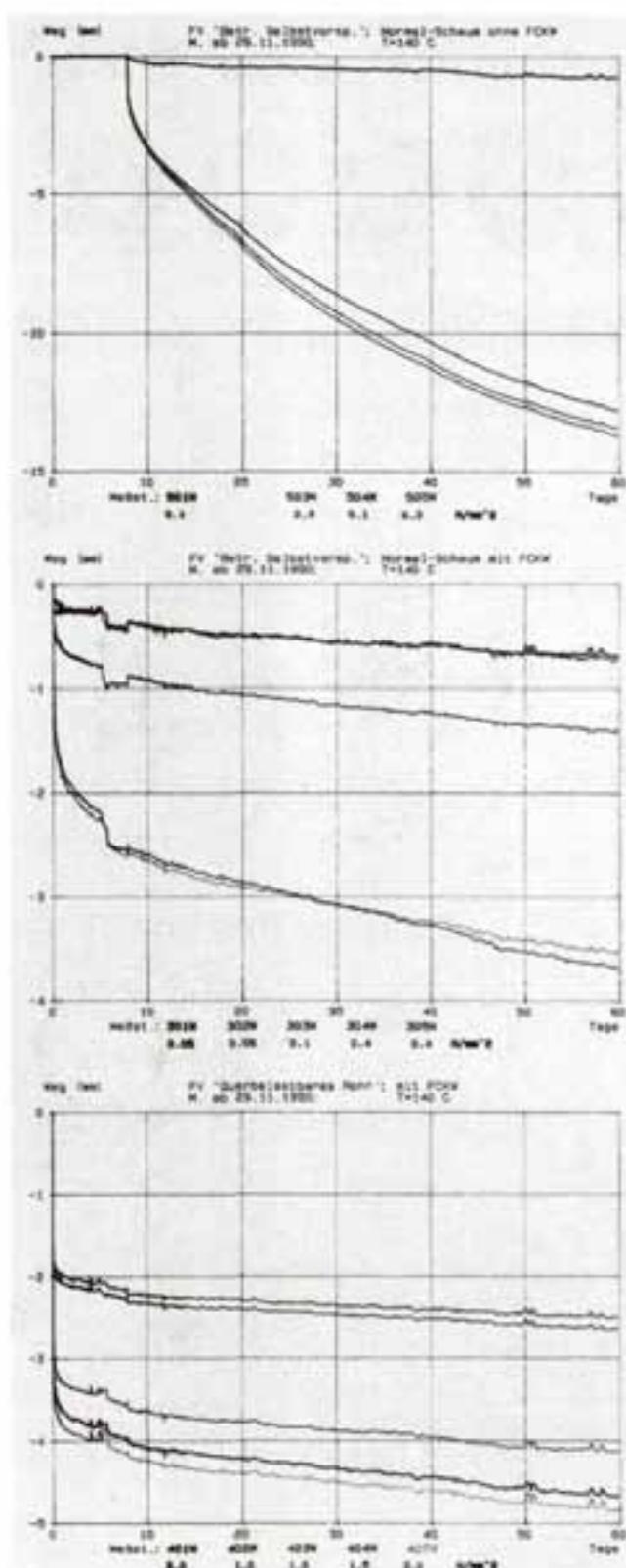
# RADIALE ZEITSTAND-DRUCKVERSUCHE VON KUNSTSTOFF-MANTELROHREN

Querbelastbares Rohr mit FCKW



ERSTE ZWISCHENERGEBNISSE  
BEI 160° CELSIUS

# RADIALE ZEITSTAND-DRUCKVERSUCHE VON KUNSTSTOFF-MANTELROHREN



ERSTE ZWISCHENERGEBNISSE  
BEI 140° CELSIUS

**RWTÜV**  
Steubenstraße 53  
W-4300 Essen 1  
Tel. (02 01) 825-26 13  
Fax. (02 01) 825-25 41

**GEW**  
Gas-, Elektrizitäts- und Wasserwerke Köln AG  
Parkgürtel 24  
W-5000 Köln 30 (Ehrenfeld)  
Tel. (02 21) 178-0  
Fax. (02 21) 178-33 22

**GEF**  
Ingenieurgesellschaft für Energietechnik  
und Fernwärme GmbH  
Ferdinand-Porsche-Str. 4 a  
W-6906 Leimen  
Tel. (0 62 24) 7 60 81  
Fax. (0 62 24) 7 71 31

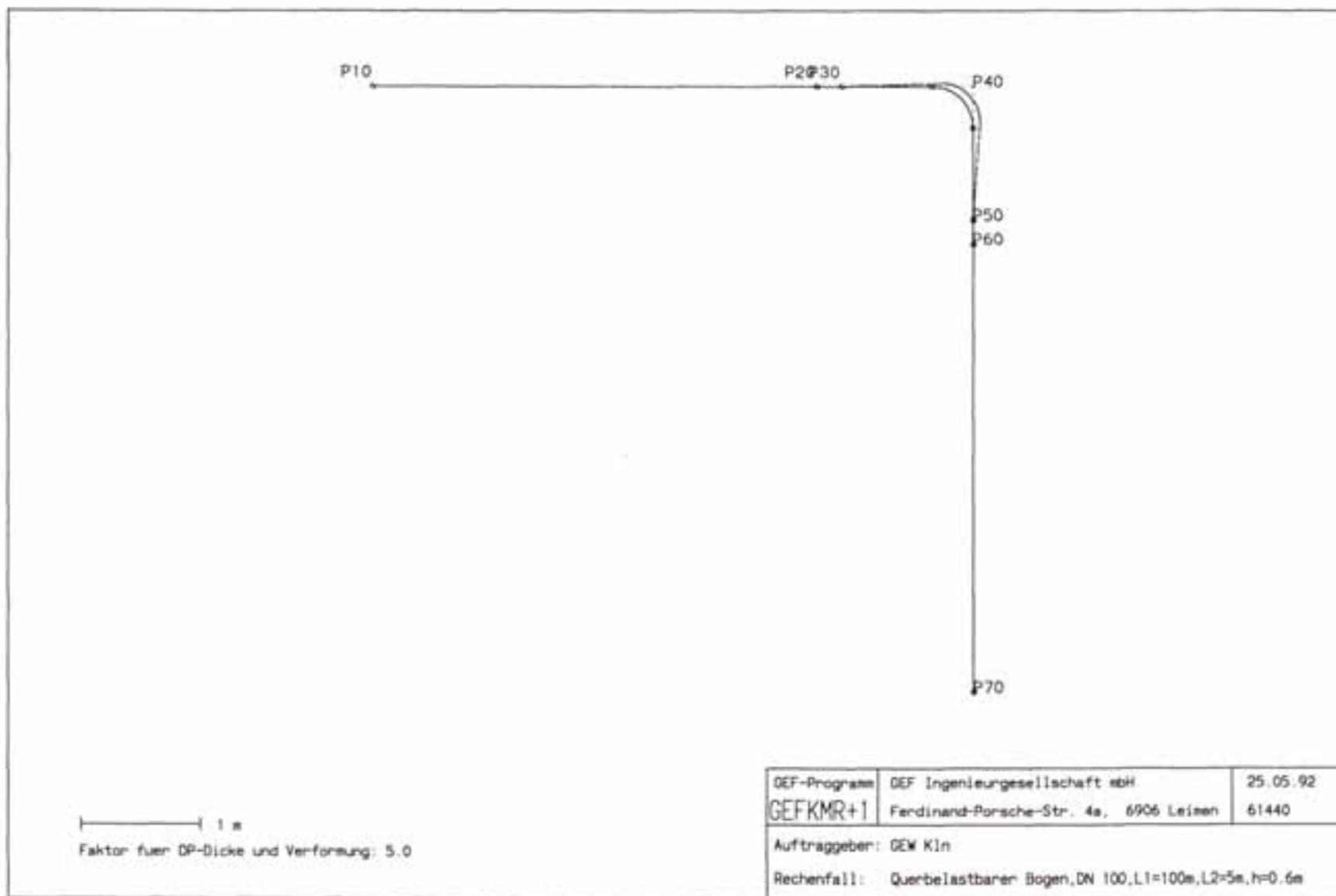
**FN**  
Fernwärme Niederrhein  
Gerhard-Molina-Str. 1  
W-4220 Dinslaken  
Tel. (0 21 34) 605-0  
Fax. (0 21 34) 605-129

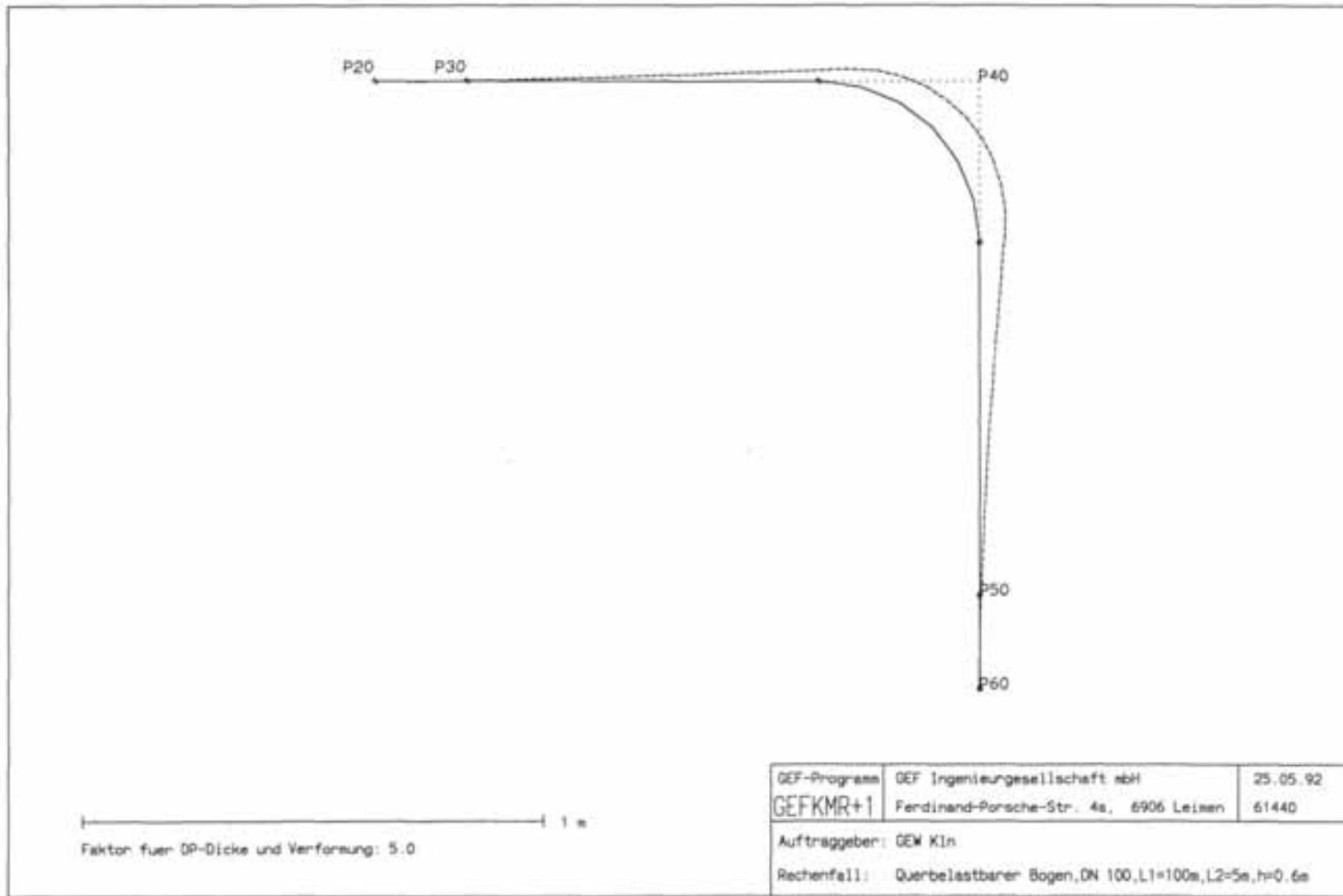
**APPENDIX 4**



— 10 m —

GEF-Programm GEFKMR+1	GEF Ingenieurgesellschaft mbH Ferdinand-Porsche-Str. 4a, 6906 Leimen	25.05.92 61440
Auftraggeber: GEW Klin		
Rechenfall: Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m		





## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

G E F K M R + 1 , Version 92.1

## Statische Berechnung von Rohr-Systemen

mit Berücksichtigung der nichtlinearen Bettungsfunktionen

\* FR'(v) - Erhöhung der axialen Reibungskraft FRg' und

\* Q'(v) - zusätzliche laterale Streckenlast

mit v - laterale Auslenkung

## B E R E C H N U N G S B A S I S

- Reduktionsverfahren mit verstärkter Ablösung der statischen Unbekannten (Sicherung numerischer Stabilität)
- Federkonstantenverfahren für iterative Erfassung der Reibung

## E I N G A B E D A T E N

Kommissions-Nr.: 61440

Auftraggeber : GEW Köln

Vorspanntemperatur.....	10.00 Grad C
Verlegetemperatur.....	10.00 Grad C
Abminderungsfaktor Reibkraft ..	0.85 -

## Abschnitt 1

Abschnitts - Anfangspunkt .....	AP
Abschnitts - Endpunkt .....	P10
Aussendurchmesser .....	114.30 mm
Wanddicke .....	3.20 mm
Mantelrohrdurchmesser .....	200.00 mm
E-Modul .....	206.00 kN/mm**2
Temperatur (max) .....	110.00 Grad C
zul. PUR-Druckspannung .....	0.15 N/mm2
innerer Überdruck .....	6.00 bar
Deckung .....	0.80 m
Winkel der inneren Reibung .....	32.50 Grad
Gamma .....	19.00 kN/m***3
Länge .....	95.00 m
Teilung .....	10 -
Bettungs-Charakter. Blatt .....	3 -

## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

Abschnitts - Anfangspunkt .....	P10	Abschnitt 2
Abschnitts - Endpunkt .....	P20	
Aussendurchmesser .....	114.30 mm	
Wanddicke .....	3.20 mm	
Mantelrohrdurchmesser .....	200.00 mm	
E-Modul .....	206.00 kN/mm**2	
Temperatur (max) .....	110.00 Grad C	
zul. PUR-Druckspannung .....	0.15 N/mm2	
innerer Überdruck .....	6.00 bar	
Deckung .....	0.80 m	
Winkel der inneren Reibung .....	32.50 Grad	
Gamma .....	19.00 kN/m**3	
Länge .....	3.70 m	
Teilung .....	10 -	
Bettungs-Charakter. Blatt .....	3 -	
Abschnitts - Anfangspunkt .....	P20	Abschnitt 3
Abschnitts - Endpunkt .....	P30	
Aussendurchmesser .....	114.30 mm	
Wanddicke .....	5.00 mm	
Mantelrohrdurchmesser .....	200.00 mm	
E-Modul .....	206.00 kN/mm**2	
Temperatur (max) .....	110.00 Grad C	
zul. PUR-Druckspannung .....	0.15 N/mm2	
innerer Überdruck .....	6.00 bar	
Deckung .....	0.80 m	
Winkel der inneren Reibung .....	32.50 Grad	
Gamma .....	19.00 kN/m**3	
Länge .....	0.20 m	
Teilung .....	2 -	
Bettungs-Charakter. Blatt .....	3 -	
Abschnitts - Anfangspunkt .....	P30	Abschnitt 4
Abschnitts - Endpunkt .....	P40	
Aussendurchmesser .....	114.30 mm	
Wanddicke .....	5.00 mm	
Mantelrohrdurchmesser .....	200.00 mm	
E-Modul .....	206.00 kN/mm**2	
Temperatur (max) .....	110.00 Grad C	
zul. PUR-Druckspannung .....	1.00 N/mm2	
innerer Überdruck .....	6.00 bar	
Deckung .....	0.80 m	
Winkel der inneren Reibung .....	32.50 Grad	
Gamma .....	19.00 kN/m**3	
Länge .....	1.10 m	
Teilung .....	4 -	
Bettungs-Charakter. Blatt .....	3 -	
Ablenkwinkel .....	90.00 Grad	
Bogen-Radius .....	345.00 mm	
Bogen-Wanddicke .....	6.30 mm	

## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

	Abschnitt 5
Abschnitts - Anfangspunkt .....	P40
Abschnitts - Endpunkt .....	P50
Aussendurchmesser .....	114.30 mm
Wanddicke .....	5.00 mm
Mantelrohrdurchmesser .....	200.00 mm
E-Modul .....	206.00 kN/mm**2
Temperatur (max) .....	110.00 Grad C
zul. PUR-Druckspannung .....	1.00 N/mm2
innerer Überdruck .....	6.00 bar
Deckung .....	0.80 m
Winkel der inneren Reibung .....	32.50 Grad
Gamma .....	19.00 kN/m**3
Länge .....	1.10 m
Teilung .....	4 -
Bettungs-Charakter. Blatt .....	3 -
	Abschnitt 6
Abschnitts - Anfangspunkt .....	P50
Abschnitts - Endpunkt .....	P60
Aussendurchmesser .....	114.30 mm
Wanddicke .....	5.00 mm
Mantelrohrdurchmesser .....	200.00 mm
E-Modul .....	206.00 kN/mm**2
Temperatur (max) .....	110.00 Grad C
zul. PUR-Druckspannung .....	0.15 N/mm2
innerer Überdruck .....	6.00 bar
Deckung .....	0.80 m
Winkel der inneren Reibung .....	32.50 Grad
Gamma .....	19.00 kN/m**3
Länge .....	0.20 m
Teilung .....	2 -
Bettungs-Charakter. Blatt .....	3 -
	Abschnitt 7
Abschnitts - Anfangspunkt .....	P60
Abschnitts - Endpunkt .....	P70
Aussendurchmesser .....	114.30 mm
Wanddicke .....	3.20 mm
Mantelrohrdurchmesser .....	200.00 mm
E-Modul .....	206.00 kN/mm**2
Temperatur (max) .....	110.00 Grad C
zul. PUR-Druckspannung .....	0.15 N/mm2
innerer Überdruck .....	6.00 bar
Deckung .....	0.80 m
Winkel der inneren Reibung .....	32.50 Grad
Gamma .....	19.00 kN/m**3
Länge .....	3.70 m
Teilung .....	10 -
Bettungs-Charakter. Blatt .....	3 -

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

## E R G E B N I S S E

## Schnittgrößen

u mm - Verschiebung axial, positiv: in Berechnungsrichtung  
 v mm - Verschiebung lateral, positiv: horizontal nach rechts  
 psi mrad - Verdrehung um vertikale Achse, positiv: rechtsdrehend  
 M kNm - Biegemoment am pos. Schnittufer, pos. Richtung wie psi  
 N kN - Kraft axial dto., pos. = Zugbelastung  
 Q kN - Querkraft dto.  
 SIGV MPa - Vergleichsspannung (Maximum aus Berechnungen an Innen- und Außenfaser in 10-grd-Schritten in Umfangsrichtung, örtl. Spannungsfaktoren nach ASME)

## Weitere Ergebnisse und Angaben

FRg' kN/m - axiale Reibungskraft - gesamt  
 Q'(v) kN/m - zusätzliche laterale Streckenlast durch v-Verschiebung  
 SNR - Schnittnummer innerhalb eines Abschnittes  
 KZ = G - Kennzeichen für geraden Bereich  
 KZ = B - Kennzeichen für Bogen

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
von: AP bis: P10 , Abschnitt 1										
0	G	0.0	0.0	0.0	0.0	0.0	0.00	-254.26	0.00	238.1
1	G	0.0	0.0	0.0	0.0	-0.0	-0.00	-254.24	0.00	238.1
2	G	0.0	0.0	0.0	-0.0	0.0	0.00	-254.13	-0.00	238.0
3	G	0.1	0.0	0.0	-0.0	-0.0	-0.00	-253.79	0.00	237.7
4	G	0.2	0.0	0.0	-0.0	0.0	0.00	-252.77	-0.00	236.8
5	G	0.5	0.0	0.1	0.0	-0.0	-0.00	-249.75	0.00	234.1
6	G	1.4	0.0	0.4	0.0	0.0	0.00	-240.77	-0.00	226.0
7	G	3.2	0.0	1.3	0.0	-0.0	-0.00	-218.72	0.00	206.3
8	G	3.3	0.0	3.4	-0.0	0.0	0.00	-187.81	-0.00	178.6
9	G	3.3	0.0	6.8	-0.0	-0.0	-0.00	-156.51	0.00	150.6
10	G	3.3	0.0	11.4	-0.0	0.0	0.00	-125.03	-0.00	122.4
von: P10 bis: P20 , Abschnitt 2										
0	G	3.3	0.0	11.4	-0.0	0.0	0.00	-125.03	-0.00	122.4
1	G	3.3	0.0	11.6	0.0	0.0	0.00	-123.80	-0.00	121.3
2	G	3.3	0.0	11.9	0.0	-0.0	-0.00	-122.57	0.00	120.2
3	G	3.3	0.0	12.1	0.0	0.0	0.00	-121.34	-0.00	119.1
4	G	3.3	0.0	12.3	0.0	-0.0	-0.00	-120.11	0.01	118.1
5	G	3.3	0.0	12.5	-0.0	0.0	0.01	-118.88	-0.04	117.3
6	G	3.3	0.0	12.7	0.0	-0.0	-0.04	-117.65	0.15	117.2
7	G	3.3	0.0	12.9	0.0	0.0	0.16	-116.43	-0.55	120.0
8	G	3.3	0.0	13.2	0.0	-0.2	-0.60	-115.20	2.06	133.5
9	G	3.3	0.0	13.4	0.0	0.7	2.24	-113.97	-7.67	186.7
10	G	3.6	5.3	13.6	0.2	-1.1	-5.68	-112.68	22.37	308.3
von: P20 bis: P30 , Abschnitt 3										
0	G	3.7	5.3	13.6	0.2	-1.1	-5.68	-113.04	22.37	202.5
1	G	3.3	0.0	13.7	0.0	-2.4	-7.94	-112.69	22.64	248.8
2	G	4.3	9.3	13.8	-0.3	-3.8	-7.05	-112.31	-9.37	237.3

## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
von: P30 bis: P40 , Abschnitt 4										
0 G	4.3	9.3	13.8	-0.3	-3.8	-7.05	-112.31	-9.37	237.3	
1 G	13.9	31.2	13.9	-1.2	-6.0	-5.11	-110.58	-13.20	213.0	
2 G	20.8	51.5	14.1	-2.5	-7.3	-2.07	-107.30	-21.00	161.8	
3 G	26.0	66.7	14.2	-3.9	-7.1	2.81	-102.88	-32.16	176.4	
4 G	29.2	76.2	14.4	-5.1	-4.8	10.07	-97.67	-45.64	341.6	
0 B 29.2 76.2 14.4 -5.1 -4.8 10.07 -97.92 -45.64 412.3										
1 B	33.8	89.5	13.4	-7.5	-2.8	12.21	-102.43	-33.57	493.2	
2 B	36.6	97.5	12.2	-9.6	-0.4	13.69	-104.85	-21.53	549.3	
3 B	38.3	102.4	10.6	-11.3	2.3	14.53	-105.27	-9.62	581.4	
4 B	39.3	105.5	8.7	-12.6	5.0	14.74	-103.77	1.99	590.2	
5 B	39.9	107.2	6.7	-13.5	7.7	14.33	-100.44	13.09	576.6	
5 B	39.9	107.2	6.7	-13.5	7.7	14.33	-100.44	13.09	576.6	
6 B	40.2	108.0	4.6	-13.9	10.2	13.34	-95.40	23.46	542.0	
7 B	40.0	107.8	2.5	-13.8	12.6	11.81	-88.80	32.90	488.2	
8 B	15.1	106.7	0.4	-13.3	14.6	9.81	-81.48	41.23	417.2	
9 B	39.7	104.7	-1.6	-12.4	16.2	7.38	-75.09	48.50	331.6	
10 B	38.4	101.5	-3.4	-11.1	17.3	4.58	-69.05	55.04	234.5	
von: P40 bis: P50 , Abschnitt 5										
0 G	38.4	101.5	-3.4	-11.1	17.3	4.58	-68.80	55.04	220.5	
1 G	34.5	90.4	-3.2	-7.8	17.4	-4.00	-75.68	36.94	221.7	
2 G	28.5	72.9	-3.1	-4.7	15.0	-9.36	-81.63	21.52	328.6	
3 G	19.6	47.3	-2.9	-2.2	11.2	-12.13	-86.17	10.18	369.4	
4 G	6.2	15.3	-2.7	-0.5	6.6	-13.21	-88.61	4.28	365.9	
von: P50 bis: P60 , Abschnitt 6										
0 G	6.2	15.3	-2.7	-0.5	6.6	-13.21	-88.61	4.28	365.9	
1 G	3.4	0.0	-2.6	0.0	4.1	-13.56	-89.08	3.51	360.1	
2 G	4.3	8.8	-2.6	0.3	1.9	-9.70	-89.46	-38.18	280.7	
von: P60 bis: P70 , Abschnitt 7										
0 G	4.2	8.8	-2.6	0.3	1.9	-9.70	-89.10	-38.18	426.4	
1 G	3.3	0.0	-2.3	-0.0	-1.2	3.83	-90.51	-36.55	218.3	
2 G	3.3	0.0	-2.0	-0.0	0.3	-1.03	-91.74	13.11	126.6	
3 G	3.3	0.0	-1.8	-0.0	-0.1	0.27	-92.98	-3.51	102.8	
4 G	3.3	0.0	-1.5	-0.0	0.0	-0.07	-94.22	0.94	97.3	
5 G	3.3	0.0	-1.3	-0.0	-0.0	0.02	-95.45	-0.25	96.6	
6 G	3.3	0.0	-1.0	-0.0	0.0	-0.01	-96.69	0.07	97.2	
7 G	2.5	0.0	-0.8	-0.0	-0.0	0.00	-97.77	-0.02	98.1	
8 G	1.7	0.0	-0.5	-0.0	0.0	-0.00	-98.55	0.00	98.7	
9 G	0.8	0.0	-0.2	-0.0	-0.0	0.00	-99.01	-0.00	99.1	
10 G	0.0	0.0	-0.0	-0.0	-0.0	-0.00	-99.16	0.00	99.3	

## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

## Ergebnisauszug (Maximalwerte)

## 1. PUR-Schaum und Mantelrohr

ANR - Abschnittsnummer  
 TAUPUR MPa - PUR-Scherspannung  
 SIGPUR MPa - PUR-Druckspannung  
 übrige Bezeichnungen wie zuvor

ANR	KZ	FRg'	TAUPUR	Q'(v)	SIGPUR		SDP
					vorh.	zul.	
1 G	-3.3	-0.009	0.0	0.0000	0.1500	0	
2 G	-3.6	-0.010	-5.3	0.0464	0.1500	0	
3 G	-4.3	-0.012	9.3	0.0816	0.1500	0	
4 G	-29.2	-0.081*	76.2	0.6665	1.0000	0	
4 B	-40.2	-0.112*	108.0	0.9446	1.0000	0	
5 G	38.4	0.107*	101.5	0.8879	1.0000	0	
6 G	6.2	0.017	15.3	0.1338	0.1500	0	
7 G	4.2	0.012	-8.8	0.0771	0.1500	0	
zul. Werte:		0.030					

## G E F I n g e n i e u r g e s e l l s c h a f t m b H

Querbelastbarer Bogen, DN 100, L1=100m, L2=5m, h=0.6m

## 2. Stahlrohr

## 2.1. Maximale Umfangsspannung aus Innendruck und Ringbiegebelastung

PHI Grad - Umfangswinkel

P bar - Innendruck

SIGT(P) MPa - Umfangsspannung infolge Innendruck

SIGT(Rb) MPa - Ringbiegespannung infolge Querpressung

SIGT - SIGT(P) + SIGT(Rb)

zul. SIGT MPa - zulässige Tangentialspannung

ANR	SNR	KZ	PHI	P	SIGT(P)	SIGT(Rb)	SIGT	zul.	SIGT
5	0	G	90	0.00	0.0	66.7	66.7	140.0	
5	0	G	90	6.00	6.6	65.7	72.3	140.0	

2.2. Detaillierte Spannungsanalyse  
am Ort mit der maximalen Vergleichsspannung

Spannungsermittlung und Bewertung nach ASME und AD-S2

Die maximale Vergleichsspannung tritt auf in

ANR SNR KZ PHI Faser  
4 4 B 180 außen

Spannungsart (in MPa)	i	SIG..
Nennspannung infolge Innendruck	1.0000	5.20
Tangentialspannung		590.15
Axialspannung		110.89
Radialspannung		0.00
Ringbiegespannung	0.0621	53.50
Gesamtspannung		590.16
zulässiger Wert		918.00

# **IEA District Heating**

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