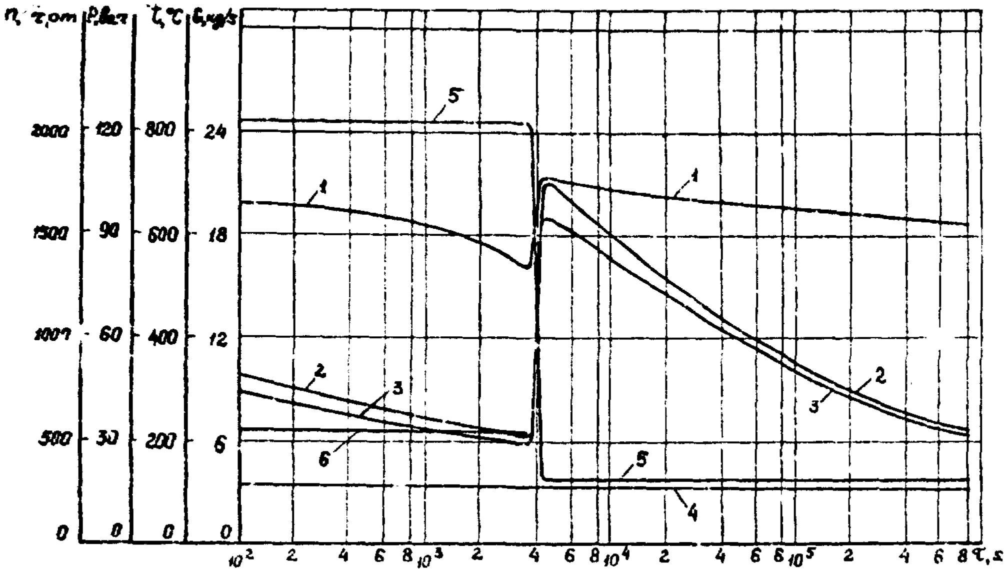

Fig. 8. The time-dependent behaviour of the HTP-300 circuit parameters when operating in a residual heat removal mode : 1 - average gas pressure in the circuit; 2 - temperature of fuel element cladding; 3 - gas temperature at the core outlet; 4 - gas temperature at the core inlet; 5 - mass flowrate of gas through the core; 6 - frequency of gas blower rotation.

INVESTIGATIONS OF GAS EXPLOSIONS IN A NUCLEAR COAL GASIFICATION PLANT

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1. Introduction

The safety research program on gas cloud explosions is performed in the context of the German nuclear coal gasification program, more precisely: in the context of the PNP project, that means, Prototype Plant Nuclear Process Heat.

By the work within this project, it is tried to extend the use of nuclear energy to non-electric applications. The product of the planned plants is SNG, that means, Substitute Natural Gas.

The use of process heat in chemical processes requires short distances between the process heat and the chemical plant. When the process heat is generated by a nuclear reactor, the safety implications of this close coupling are obvious, if one remembers the serious accidents in Flixborough, Port Hudson, or de Beek, Netherlands.

At the present time, nuclear power is mainly used to produce electricity. In Germany, the licensing procedure of nuclear power stations must prove that the impact of pressure waves cannot cause serious damage to the nuclear reactor. For this purpose, the licensing authorities have worked out a regulatory guideline, which postulates a certain pressure resistant design of the reactor building, and - what is important here - certain safety distances. In the case of gas mixtures as explosives, these safety distances between reactor building and the location of potential gas flow-out depend on the mass of this gas.

These safety distances are incompatible with the technical requirement of handling process gases in close distance to or inside the reactor building, in order to be able to use the necessary high temperature.

The two chemical processes, which will be supported by nuclear heat, are the methane steam reforming process +) and the steam gasification of coal ++). In order to achieve a reasonable throughput the temperatures necessary for these processes are in the range of about 900 °C. If this high temperature heat must be transported over some distance, there are considerable losses of heat. As a consequence one must start at higher temperatures. The starting temperature is approximately the temperature of the nuclear reactor, which is limited by the materials used.

On the other hand, at the time, when the regulatory guideline was worked out, there were some incertainties about the mechanisms and possible impacts of gas cloud explosions.

For these reasons the guideline explicitely excludes future nuclear process heat plants. These plants will be designed, constructed, and operated in order to prevent a dangerous release of gas as far as possible. Nevertheless, it must be shown in the nuclear licensing procedure that a gas release cannot cause serious damage to the reactor plant. The program shall supply sufficient knowledge in order to protect the reactor plant adequately.

+) in the case of hydrogasification

++) in the case of steam gasification

2. Philosophy, Structure and Organisation

2.1 Detonation and Deflagration

Some time ago, it was found that a flammable cloud can principally explode in two very different processes /9, 10/. One process, well known from high explosives, is the detonation. In a detonation, the flammable gas mixture is ignited by the temperature rise due to the generated shock wave. Shock wave and flame front are coupled and travel with supersonic velocity through the cloud. The primary ignition must have sufficient power and the mixture must be able to burn quickly enough.

In a detonative wave, the pressure rises abruptly and decreases - compared with the deflagration - relatively quickly. The peak values of the pressure depend on the energy density of the exploding mixture and can reach about 10 bar; in gas explosions typical durations are about 50 msec.

The other explosion process is the deflagration. In a deflagration, the reaction front propagates with moderate velocity behind the generated pressure wave. The flame-velocity in case of turbulent flow may be in the order of 10 m/sec relative to the unburnt mixture.

As the reaction products have a volume which is by a factor of approximatly 7 larger than that of the unburnt mixture, they leave the reaction front with a velocity of 70 m/sec. If they cannot flow away freely - and this is the situation in the spheric case -, the reaction front must travel with the enhanced velocity of the reaction products into the unburnt mixture, acting like a (spheric) piston of nearly the same velocity.

In the deflagrative wave, the pressure rises slowly to the peak pressure; outside of the burning cloud, this overpressure quickly changes to an underpressure of nearly the same (absolute) value from which atmospheric pressure is reached slowly. Maximum over- and underpressure are nearly equal and are determined by the velocities of the flame front (or the piston). In the above mentioned case of 70 m/sec flame front velocity, a peak overpressure of 60 mbar is generated. The total duration of the wave is determined by the flame front velocity and the extension of the cloud; in a centrally ignited cloud of 35 m radius, a totel duration of 500 msec is achieved.

2.2 Structure of the program

For explosions of TNT and other high explosives, a relationship was derived between the damage of typical structures and the destroying pressure. Analysing the hazards of gas cloud explosions with this relationship, leads to two remarkable results:

- The destroying pressure must have been considerably higher than that of an ideal, undisturbed deflagration - supporting the assumption of a process similar to a detonation.

- The second result is, that the equivalent TNT-mass (which would generate such a damage) drops towards short distances from explosion centre: this result is contradictionary to the asumption, that the destruction was performed by a detonation generated blast wave.

The disagreement between the two results of usual damage analysis reflects the uncertainties in our field and determines the work to be done.

(1) First, it is necessary to find the pressure and the pressure shape of realistic gas explosions. Today, I guess, all experts agree to the fact, that a gas cloud cannot detonate, if three conditions are fulfilled:

- the cloud is completely unconfined,
- the cloud is mixed of air and hydrocarbons (with at most one double bond),
- the cloud is not ignited by a detonation e.g. of a high explosive.

In general, two of these conditions (gas composition and no strong ignition) are fulfilled. Partially confining structures within or near the cloud can disturb and accelerate the deflagration process and perhaps cause a transition to detonation.

In the first part of the researchprogram, the acting mechanisms are investigated, which can influence the pressure build-up.

(2) Comparing the pressure shapes of a detonation and a deflagration, a different behaviour of the structures submitted to these waves is expected.

In a second part, the impact of pressure waves of realistic shape on some structures is determined. Such structures are chosen which are often used to analyse explosion accidents. Actual damage is to be compared with damage to be expected by deflagrative processes.

There are two other parts in the program:

(3) In a third part some work had been done in compiling some relevant data on accidental gas explosions.

(4) There is a fourth part, too.
In this part the research and development work is judged with respect to safety implications and a safety concept has to be worked out. In the context of this concept, we discuss the interesting proposal to ignite the gases in case of major gas release, before an explosive cloud may form; the underlying idea is that a large fire can better be coped with than an explosion.

2.3 Organisation and time schedule

The work of this program is performed in cooperation with a number of expert institutes acting as GHT subcontractors (Tab. 1).

The program started with its first phase in the last quarter of 1977; in this phase, mainly the work of the following stage had to be defined. The second phase started a year later; the work of this phase will be completed by mid 1981.

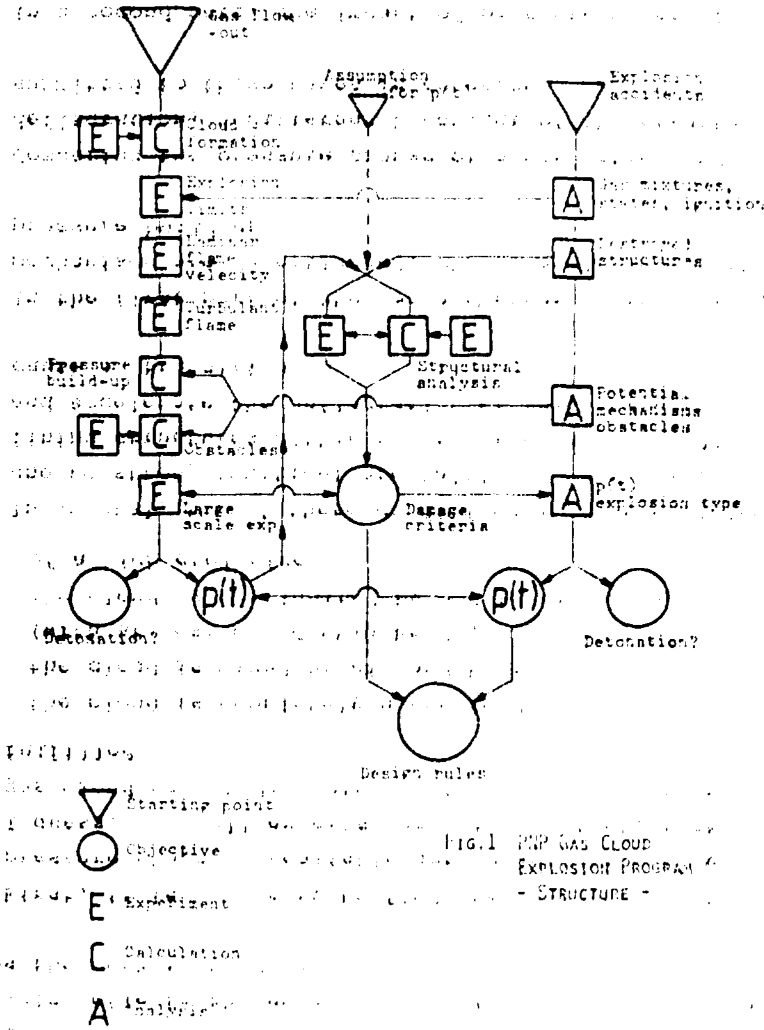


FIG.1 PNP GAS CLOUD EXPLOSION PROGRAM - STRUCTURE -

1.1 FORMATION OF EXPLOSIVE CLOUDS
PROF. K R E M E R , GAS-WÄRME-INSTITUT (GWI), ESSEN

1.2 EXPLOSION LIMITS AND FLAME VELOCITIES
PROF. H O F M A N N , INSTITUT FÜR TECHNISCHE CHEMIE I, UNIVERSITÄT ERLANGEN

1.3 PRESSURE BUILD-UP
PROF. E B E R T , INSTITUT FÜR MECHANISCHE VERFAHRENSTECHNIK UNIVERSITÄT KAISERSLAUTERN

1.4 INFLUENCE OF OBSTACLES
DR. G E I G E R , BATTELLE-INSTITUT, FRANKFURT

2.1 STRUCTURAL DYNAMICS EXPERIMENTS
DI. H O F F M A N N , ERNST-MACH-INSTITUT (EMI), WEIL/FREIBURG

2.2 STRUCTURAL DYNAMICS CALCULATIONS
DR. R I S C H B I E T E R , BATTELLE-INSTITUT, FRANKFURT

2.3 LARGE-SCALE EXPERIMENTS AND DAMAGE CRITERIA
DR. P F Ö R T N E R , INSTITUT FÜR CHEMIE DER TREIB- UND EXPLOSIVSTOFFE (ICT), KARLSRUHE-PFINZTAL

3 DESIGN RULES AND GUIDELINES
PROF. S C H Ö N , PHYSIKALISCH-TECHNISCHE-BUNDESANSTALT (PTB) BRAUNSCHWEIG

PROF. V O I G T S B E R G E R , BUNDESANSTALT FÜR MATERIALFORSCHUNG (BAM), BERLIN

4 TECHNICAL ADVICE
DR. K O C H , KRAFTWERK UNION (KWU), ERLANGEN

TAB. 1 MAIN TASKS AND GHT SUBCONTRACTORS IN THE PNP GAS CLOUD EXPLOSION PROGRAM

3. Single mechanisms

In part I of the program, it is intended to investigate the acting mechanisms, which cause a pressure wave as a consequence of explosive gas release from the gasification plant.

3.1 Cloud formation

In section 1 of part I, the release of the gas, its propagation and the forming of the cloud are to be treated.

The following problems are not fully understood up to now.

(1) While the propagation and mixing of an undisturbed jet is known and calculable, experiments must be performed, if the jet hits an obstacle (ground, buildings).

(2) If the gas is released without directed momentum, the gas propagates near the point of release in a flow field governed by turbulence. The concentration distribution and its fluctuations are generated by steamline curvature and turbulences. The typical length scale of this turbulent flow is determined by the dimensions of buildings nearby. The concentration distribution can be calculated only for large distances, large compared with the dimensions of structures; in the neighbourhood of these structures the flow field is very complicated and only model experiments are possible.

(3) The gas release from bursting vessels can be described by a model , which has been developed by Giesbrecht et al./ 1 / for two-phase mixtures. There must be done some corrections for gas filled vessels.

(4) The buoyancy of light and hot gases will influence the forming of the cloud; there exist only spare measurements and no calculations.

(5) After gas release, the mixing state can be described by the local distribution of concentration and turbulence. The burning velocity, which immediately determines the pressure of the blast wave, is strongly influenced by these two quantities. Beyond this the further propagation of the gases will be caused by turbulence, that means short time fluctuations of concentration and the following long time dilution. Usually, the time average of concentration is calculated; concentration fluctuations and turbulence are not known.

(6) Finally the model measurements must be scaled-up to real size. At the time, there are deviations up to a factor 3 in both directions.

To remove some of these incertainties model experiments are being performed in a small wind tunnel. Fig. 2 shows the wind tunnel and the arrangement of the model buildings. The flow direction is parallel to the x-axis and to a line intersecting this axis at an angle of 30°.

The source of the gas, of which the concentration is to be measured, is situated in the lee side of the first, transverse building (Fig. 2).

Measurements have been performed to investigate

- the influence of the mode of gas release (directed or diffuse)
- the influence of an obstacle in a jet
- the influence of the source altitude
- the influence of the angle of flow relative to the model arrangement.

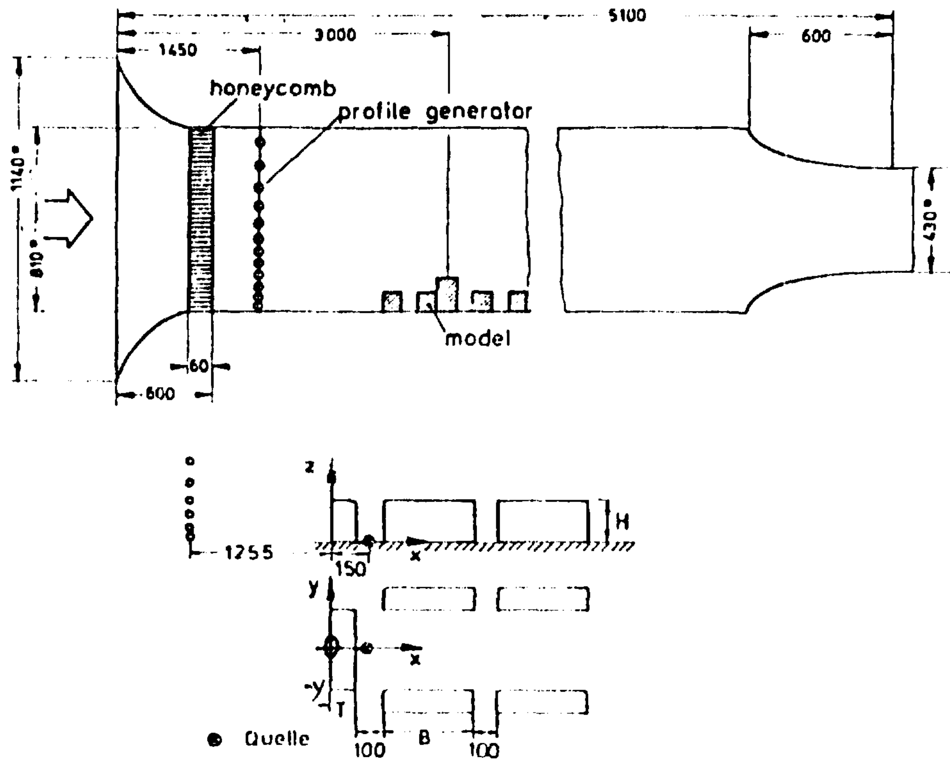


Fig. 2 a) Wind tunnel
b) Model arrangement;
coordinates for concentration distribution measurement

The first experiments for revealing the influence of bouyancy did not show any effect. For this purpose, experiments are to be performed in a room with a cross section of about 20 m^2.

Fig 3. shows the concentration field of a diffuse source at floor. The (dimensionless) concentration K is displayed as a function of altitude z at different points x, y in the horizontal plane. As the wind flows parallel to the symmetric axis, the resultant concentration distribution is symmetric, too; therefore, only one half of the data has to be displayed.

As another example Fig. 4 shows the influence of release mode. A directed release against the floor at different angles is compared with the diffuse emission of gas.

The measured data are being used to develop or improve calculation methods. With these methods the gas masses between certain concentration limits can be determined for different situations and the most severe situation can be found.

3.2 Ignition data

In the next section the questions of ignition and of laminar flame velocity are treated. Because of the enhanced temperatures and the special gas mixtures of nuclear process heat plants not all relevant data are known from literature.

The measurement of necessary explosion limits has started. Most of the work will be done in a conventional explosion chamber, some control measurements of larger scale will be carried out.

A survey of the literature on flame velocity and its measurements shows large discrepancies for some gases and between different methods. In order to limit the range of values sufficiently, we decided to build up a new measurement device. The central part is a nozzle burner. The angle of the flame cone is determined by a Schlieren optic. The velocity of the fresh burning gas is determined by the velocity measurement of very small (0,2 μm) tracer particles; this is done by a Laser-Doppler-anemometer. The first measurements have been carried out.

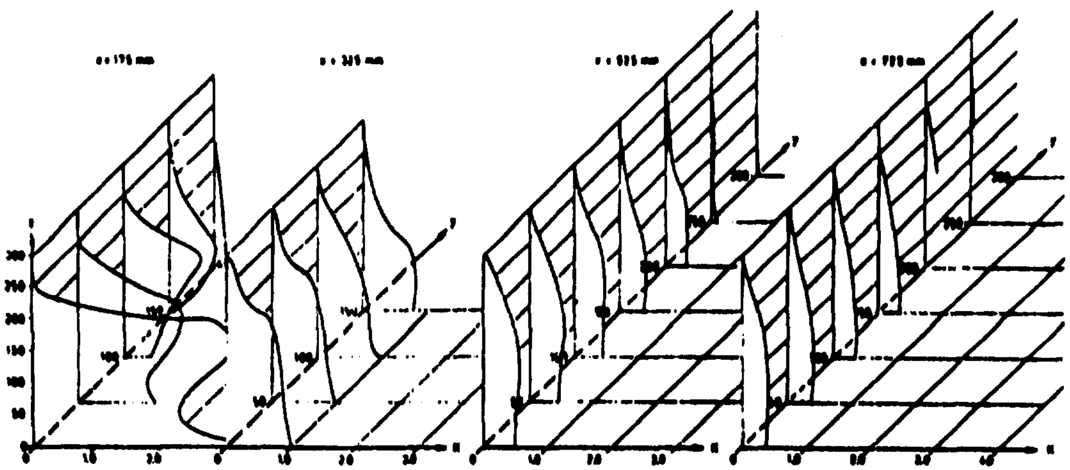


Fig. 3 Distribution of (dimensionless) concentration K; diffuse gas release at ground (see fig.2)

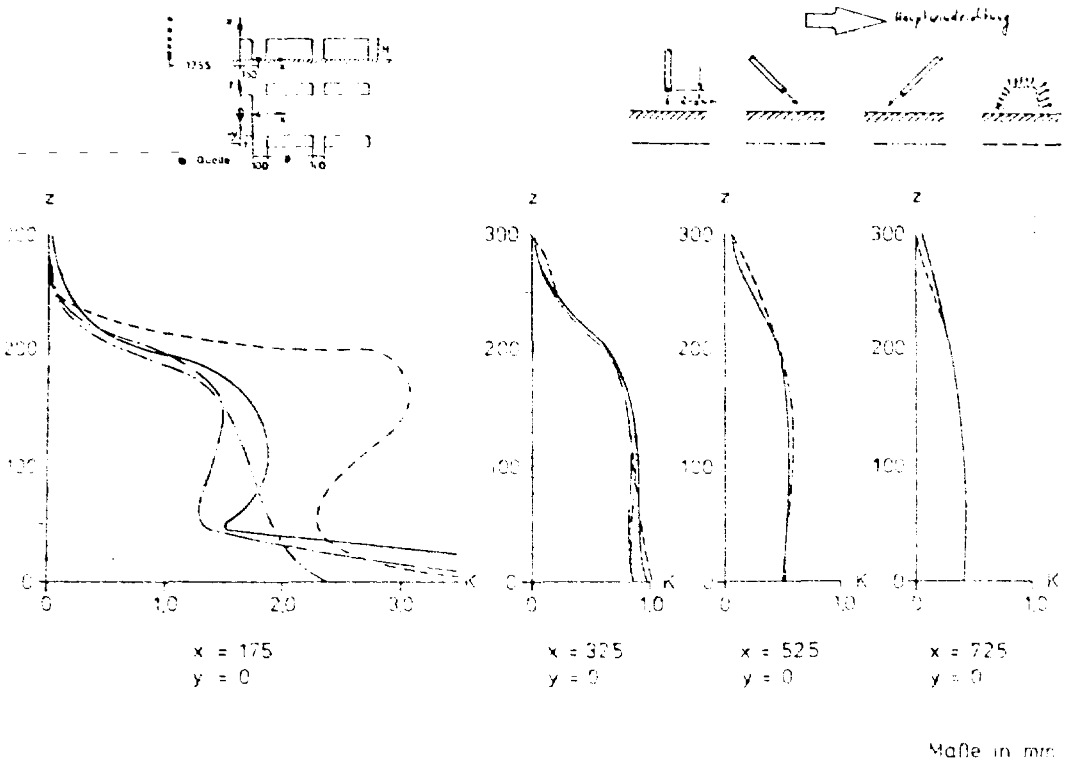


Fig. 4 Distribution of (dimensionless) concentration K: gas release at ground, mode as indicated at the upper right.

3.3 Pressure build-up calculations

In the third section of part I, a computer code is being developed. Starting point of such calculations is a set of governing differential equations. Up to now, these equations were solved only under two simplifying restraints:

- first, only geometrical configurations with one space coordinate can be described, that means only plane, cylindrical, or spherical flame fronts can be calculated;
- than, it is assumed, that the fields of pressure and flow velocity are similar.

In order to achieve a more realistic mathematical description, the two restraints are dropped: the solution shall be extended to some other important geometries (Fig. 5 a) without assuming a similarity of the two fields; the instationary propagation process shall be studied for different and changing flame velocities.

At the time, only a one-dimensional code has been developed. By this, the effect of flame velocity is studied. Before extending the code to a true two-dimensional one, some two-dimensional configurations shall be treated by perturbation methods.

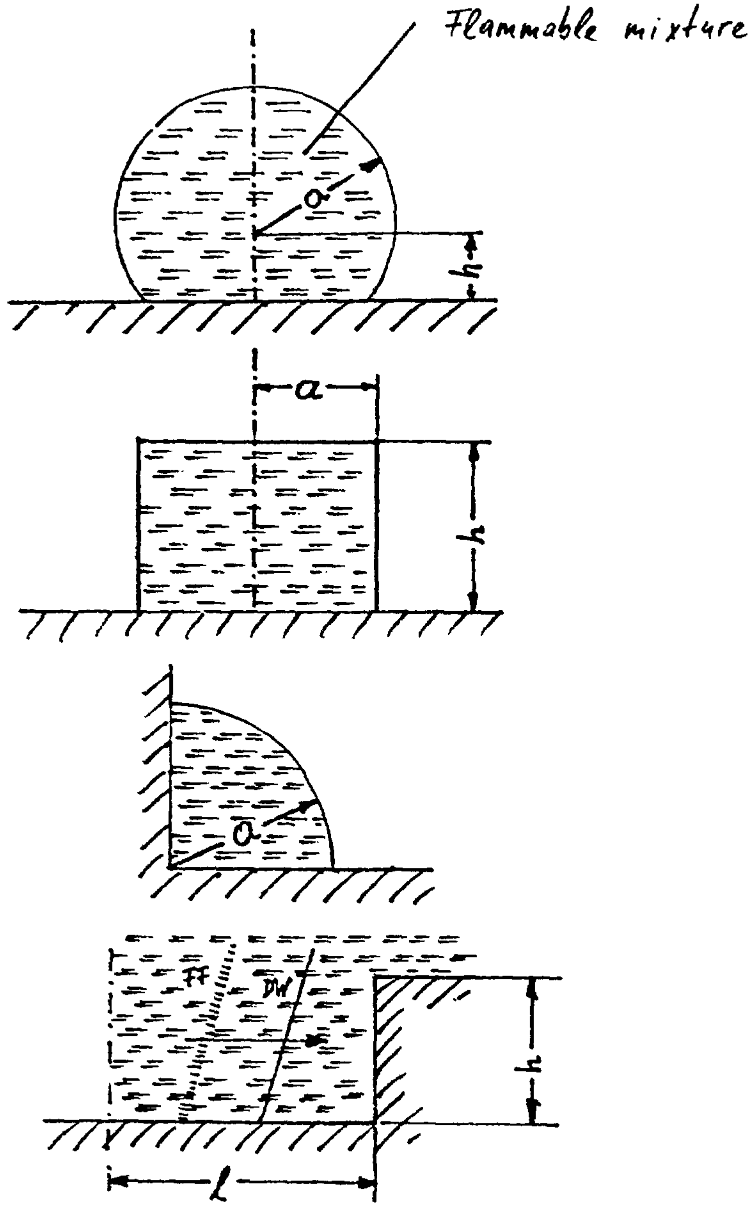


Fig. 5 a) Geometries of gas cloud and confinement for calculating the pressure build-up.
a, h, and l parameters to be varied, FF flame front, DW pressure wave

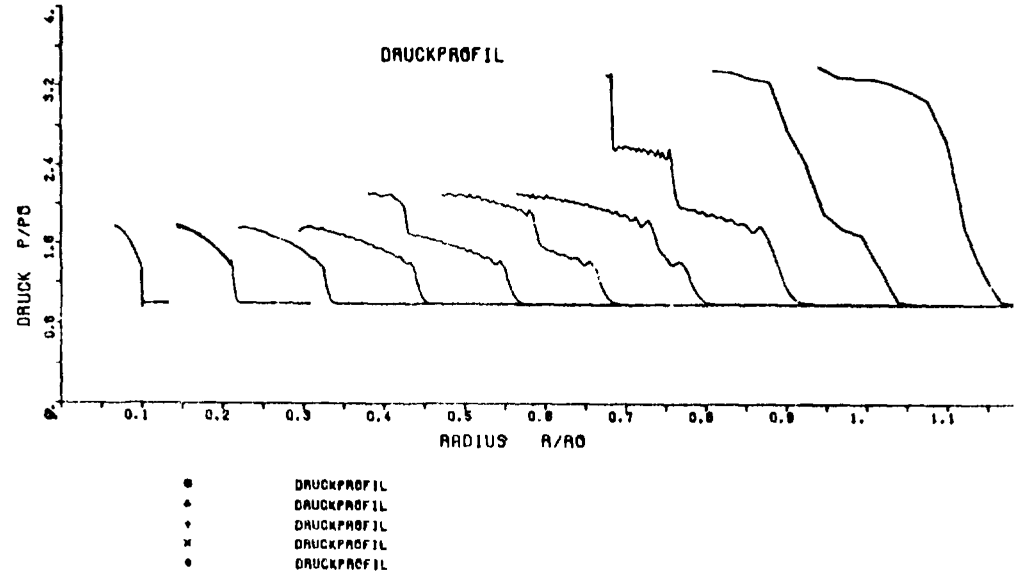


Fig. 5b) Pressure shapes of a spherical explosion at different times. An unrealistic high flame velocity of 52 m/sec leads to front velocity of 330 m/sec; after 1/3 and 2/3 of radius, this flame is a acelerated by 20%, as it may be caused by grids or nets

3.4 Obstacles

In the next section the possibilities of higher pressures caused by the interaction of the flame front with obstacles are to be proved.

In this work,6 possibilities could be identified which were able to enhance the pressure beyond that of an undisturbed deflagration.

(1) If the explosion takes place in confined or partially confined geometries, the pressure is enhanced.
- This effect can be avoided by an adequate design.

(2) If the unburnt gas flows through grids or similar structures, the turbulence in the gas increases and causes an increase of flame velocity and of pressure.

- This effect has been investigated (among others by Wagner and co-workers) and leads only to a moderate enhancement of the pressure. / 2 /

(3) A further possibility is the crossing of two flame fronts.

- Here some work was done by Smolinske. Smolinske / 3 / used shock-waves in his experiments; if one interpretes these experiments for the blast waves of gas explosions, it seems that this effect cannot strongly influence the pressure build-up.

(4) If the gas flow is reflected by obstacles, the pressure is enlarged with some small influence on the burning process.

- This effect is known and can be calculated, it is not necessary to do r & d work.

The remaining two possibilities have to be treated more deeply; for it cannot be excluded, that they are able to generate pressures considerably higher than those of ideal deflagrations.

(5) One of these two cases is the ignition of a flammable cloud by another explosion, which has taken place in a building or a vessel. The pressure wave and the gas flow of the first explosion increases the turbulence in the cloud and accelerates the burning process; on the other hand, the burning process supports the blast wave with the consequence, that its pressure drops less slowly than in the free, unburning atmosphere.

- Some experiments are planned, to analyse this phenomenon, but the main work should be done in the frame of the LWR safety research program of the federal goverment.

(6) The second issue is concerned with the vortices, which are generated, if the flow in front of the flame front hits buildings and other structures. If the flame front reaches the vortex, the flame can be drawn around by the high circulation velocity and some unburnt gas is enclosed by a cylindrical, concentric flame front.

Up to now, there is not much knowledge about the burning and explosion behaviour of vortices. Some small-scale experiments show an increase of flame velocity with the circulation of the vortex, but the pressure has not been measured. It cannot be excluded, that the concentric flame front may generate a pressure, considerably higher than undisturbed deflagrations.

In order to investigate this phenomenon, an experimental arrangement has been constructed, in which a vortex-like flow field can be generated (Fig. 6). After filling the system with a flammable mixture, a sufficient flow is fanned by means of a blower. Then blower and chamber are separated by the two slide valves, and the mixture is ignited at the periphery over the total height of the chamber. The thin side walls of the chamber are removed quickly by the increasing pressure in order to simulate a nearly unconfined explosion process.

Unfortunately, it was not possible to perform a vortex experiment till today and I can only show you some flow measurements. Fig. 7 shows some plots of the circumferential velocity and the turbulence at some positions in the chamber.

The velocity distribution is similar to that of a core of a vortex; a judgement of the turbulence distribution is not possible, because the turbulence of real vortices is not known.

The full lines in the figures show the stationary values, that means the values with running blower; the interrupted lines are measured some time after separating the blower from the chamber; these values are important for the experiment, for the gas cannot be ignited unless the blower is separated.

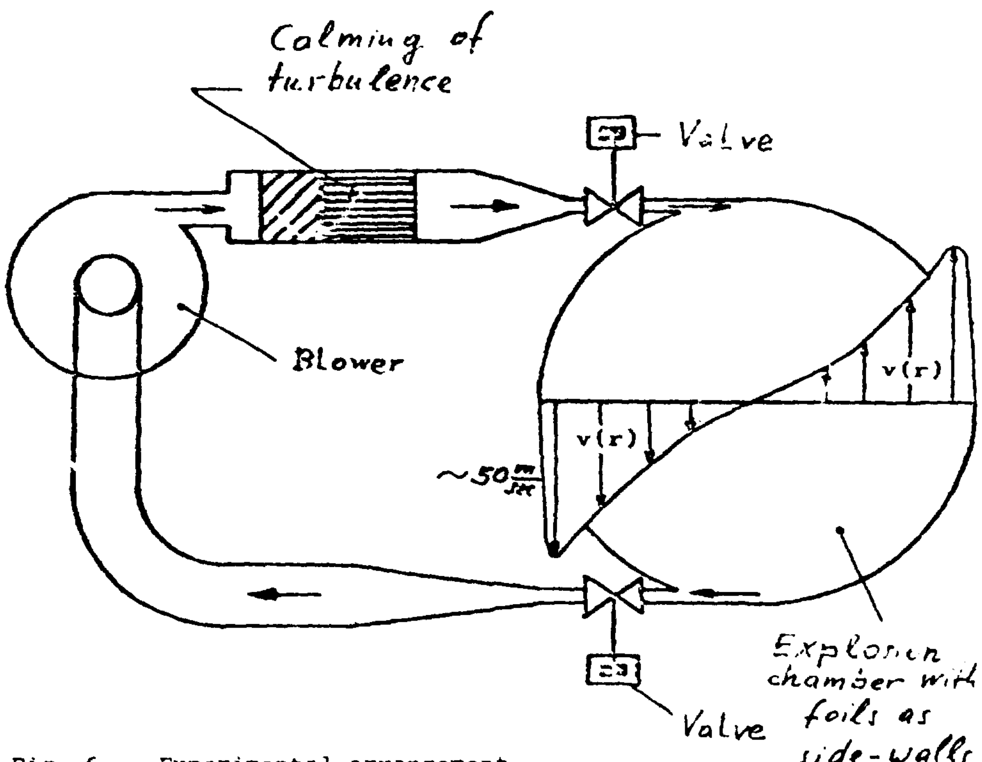


Fig. 6 Experimental arrangement for generating vortex-like flow fields.

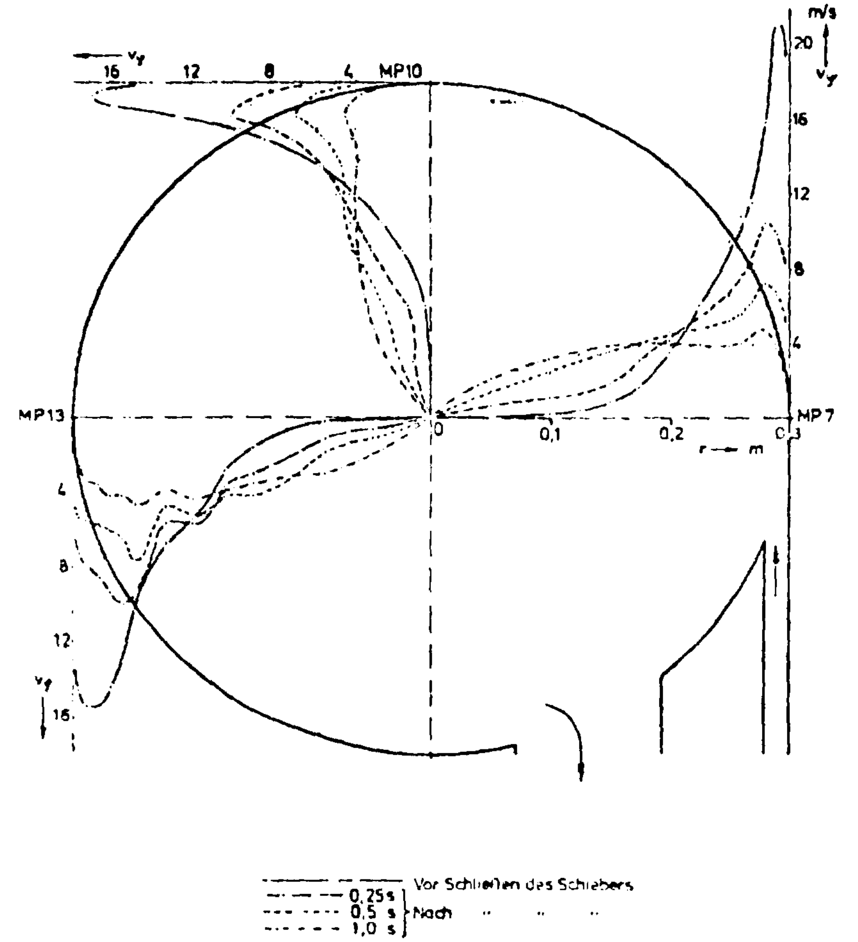


Fig 7 a) Distribution of circumferential velocity at different times (stationary and after separating the blower).

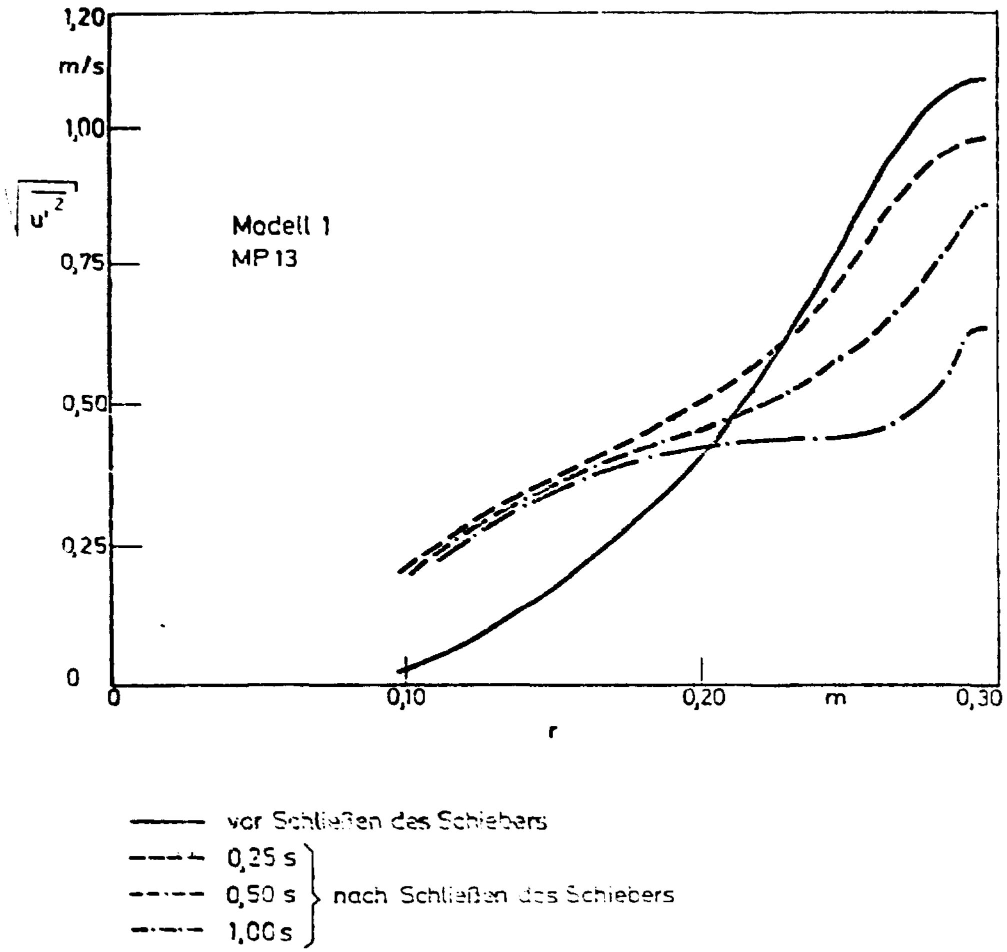


Fig. 7 b) RMS deviation of actual velocity from mean velocity at different times (stationary and after separation of the blower).

3.5 Large-scale experiments

As a last section of part I, some large-scale experiments are performed which look at the explosion process as a whole.

The experimental explosions were ignited in hemispheric baloons and in hoses, both consisting of thin polyathylene foil. The baloons and hoses were filled with nearly stoichiometric hydrogen-air-mixtures and ignited by exploding wires.

Hydrogen is used, because some of the process gases in the gasification plant have a high hydrogen concentration; additionally, it es very instructive to compare the quick burning hydrogen with the slowly burning methane which is known from other experiments.

In the baloon explosions, a nice example of agreement between a theoretical prediction and the experimental result was found. Fig. 8 a shows a calculated pressure shape of Kurylo et al. / 4 /, which can be compared with an experimental one. The theoretical curve has been corrected for distance, flame speed and density ratio.

This correction is shown in tabular form (Tab. 2). At the first arrow, a correction for distance is performed assuming acoustic behaviour of the peak pressure; this behaviour is proved by measurements.

The second arrow shows the correction of piston velocity. (The piston velocity is connected with the absolute flame velocity S_{abs} and the density ratio between unburnt and burnt mixture).

The correction is done by using an approximation of Taylor's formula for the peak pressure / 5 /.

$$p = \text{const.}\ \frac{\beta^2}{1+\beta} \approx \text{const.}\ 0.68 \cdot \beta^{1.87}$$

where β is the piston velocity divided by the sound velocity.

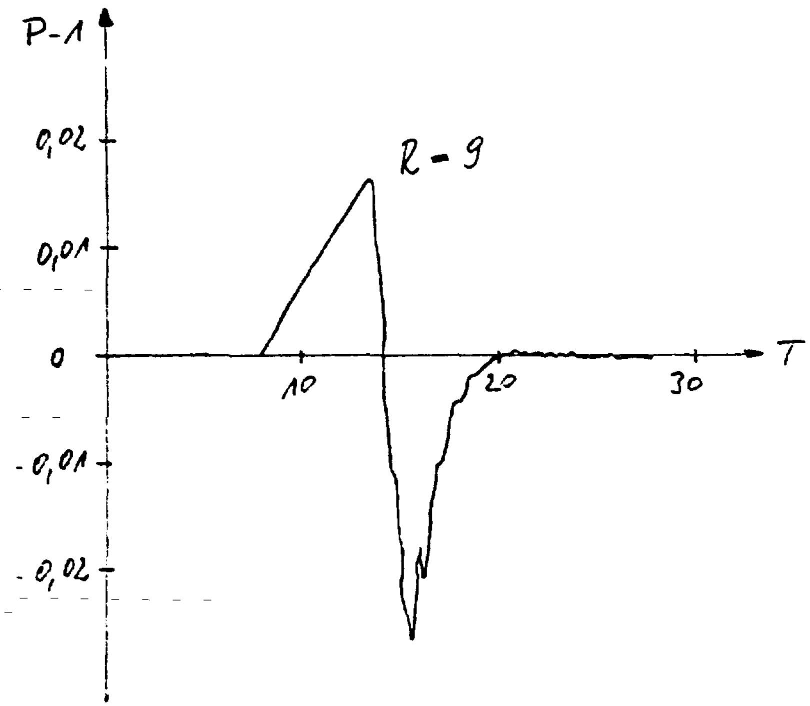


Fig. 8 a: Calculated pressure build-up;
flame speed = 10 m/sec
$P = p/p_o$, $T = t/t_c = t\ a/r_c$, $R = r/r_c$
P pressure, p_o ambient pressure,
t time from beginning of deflagration,
$t_c = r_c/a$, r distance fr· center of the cloud,
r_c radius of the unburnt cloud,
a sound velocity in the unbuiat mixture

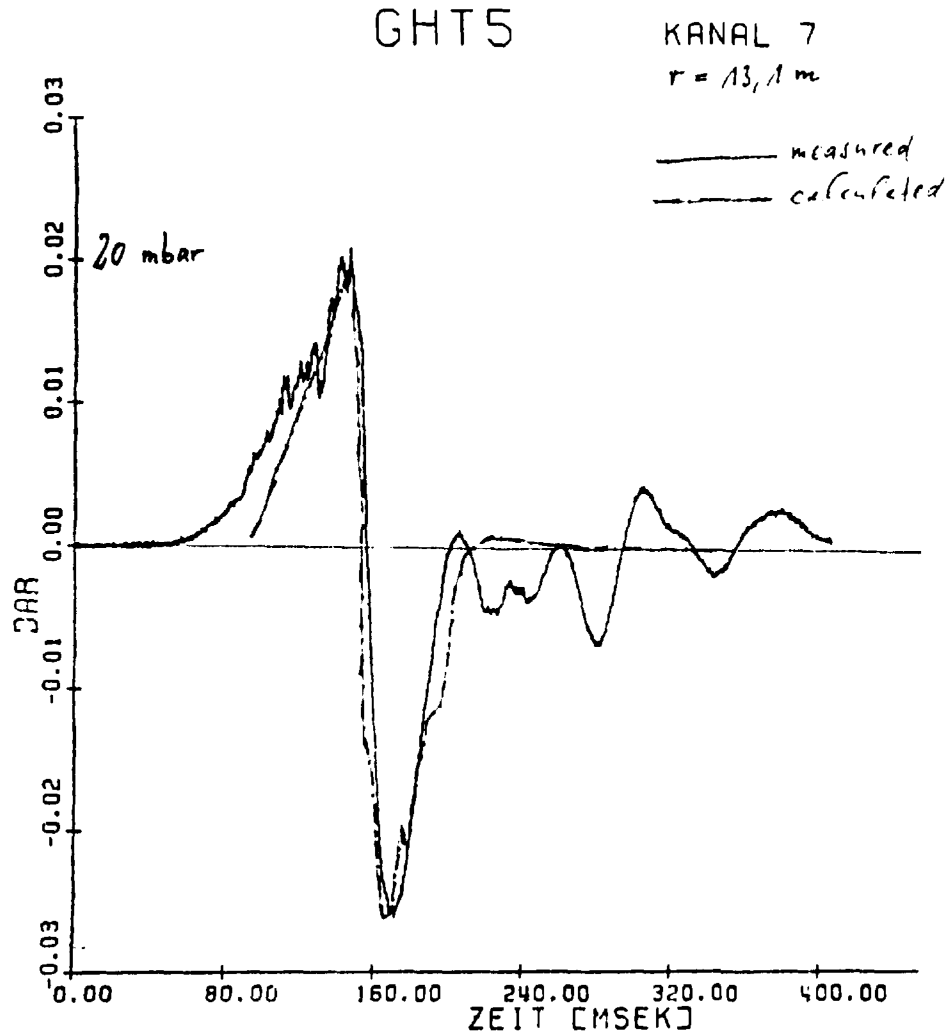


Fig. 8 b: Measured and calculated pressure-time-shape;
50 m^3 baloon of hydrogen-air-mixture;
5,8 m diameter, distance 13,1 m

		Kurylo	ICT
Δp	mbar	16,3	20,0
r	m	25,9	13,1
	$\Delta p \sim r^{-0,9}$ ⇓	Acoustic behavior proved by ICT measurements	
r'	m	13,1	
$\Delta p'$	mbar	39,1	
S_{obs}	m/sec	70	58
ρ_0/ρ_2		7	7,9
u	m/sec	60	51
	$\Delta p \sim u^{1,9}$ ⇓	Taylor's piston model proved by ICT measurements	
u''	m/sec	51	
$\Delta p''$	mbar	21,9 ≈	20,0

Tab. 2: Comparison between theoretical (Kurylo) and experimental (ICT) overpressure (see text)

The comparison of the two curves in Fig. 8 b shows a quite good agreement between the two curves in spite of the differences in shape and of the pressure bumps after the peak pressure.

The baloon experiments intend to reveal

- the influence of cloud extension and
- the influence of ignition energy

on the flame front velocity and the pressure wave.

It is known from experiments with methane and some other hydrocarbons, that the flame accelerates with path length because of the turbulence generated by the flame itself, quantitatively, the flame velocity increases with the 4th root of cloud radius.

Hydrogen explosions of balcons with 1.5, 2.9 and 5 m radii suggest, that this rule holds for hydrogen, too (Fig. 9). In order to confirm this result for an radius of nearly 10m, an experiment was planned for June, but unfortunately, it could not be performed, because there was rainy season in Germany.

On the other hand, such an acceleration of flame velocity is not alarming: a flame path length of 500 m gives a factor of 3 in velocity, hence 150 m/sec , and causes an overpresure of nearly 0.3 bar, the design over-pressure of nuclear power plants.

In order to discover a dependence from the ignition energy, the mixture was ignited by energies of 10 and of 1000 Joules of the exploding wire. No significant result could be found (Fig. 10), the effect must be smaller than the mean deviation of flame accelerations measured, which is nearly 30 %.

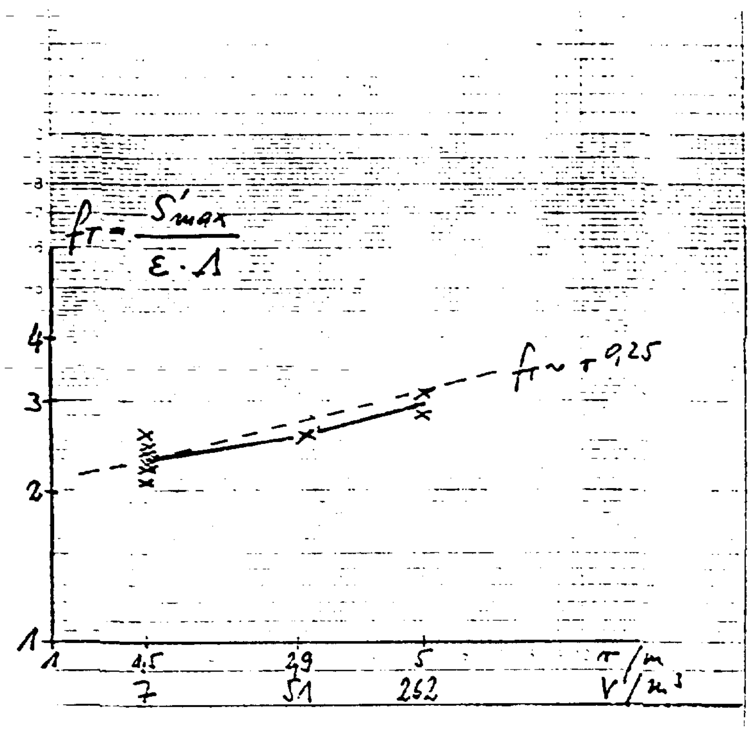


Fig. 9: Acceleration of measured flame front velocity S_{max} as a function of flame way (radius of baloon). The ordinate shows the ratio of S_{max} and $\varepsilon\Lambda$; $\varepsilon\Lambda$ would be the flame front velocity in the case of a laminar flame.

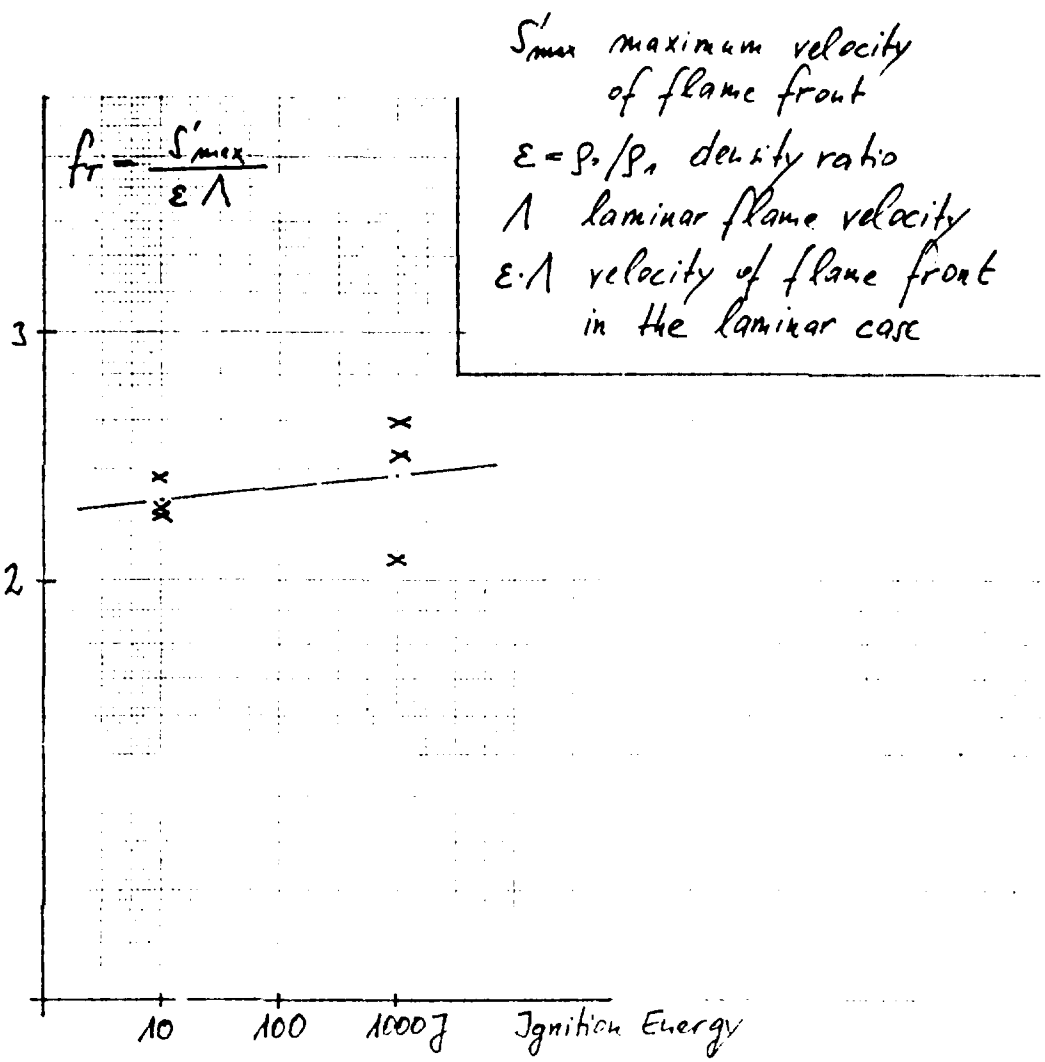


Fig. 10 : Acceleration of flame velocity relative to the laminar velocity as a function of ignition energy

In the foil hoses the susceptibility of flame velocity to turbulence and the ability to detonate should be observed.

As just reported, the deflagration of a hydrogen filled baloon is quite similar to that of a methane filled one. On the other hand, the explosion behavoiur of the two gases in inflexible tubes differs strongly; in the hydrogen filled tubes after few diameters of path length a transition from deflagration to detonation is observed, while methane has a considerably longer transition length (some 10 diameters).

In respect to confinement, a foil hose represents a medium configuration. If it is not possible to cause a transition to detonation in a hydrogen filled hose, a detonation of unconfined hydrogen-air-mixtures can be excluded as it is the case with hydrocarbon-air-mixtures.

The experiments in hoses of a length of 25 m and a diameter of 0.8 m did not show any dramatic behaviour; the maximum values of flame front velocity and peak overpressure are 52 m/sec and 13.5 mbar, respectively (Fig. 11). They can be interpreted as prove for the impossibility of unconfined hydrogen-air-detonations. As already mentioned above, this conclusion holds only, if there is no strong, that means detonative, ignition source; a unconfined homogeneous hydrogen-air-mixture slightly rich of stoicheiometric will detonate, if ignited by about 1 g of a high explosive like Tetryl / 6 /.

For the near future following experiments are planned

- the above mentioned explosion of a large baloon of nearly 10 m radius,

- the ignition of hydrogen-air-mixtures within two walls;

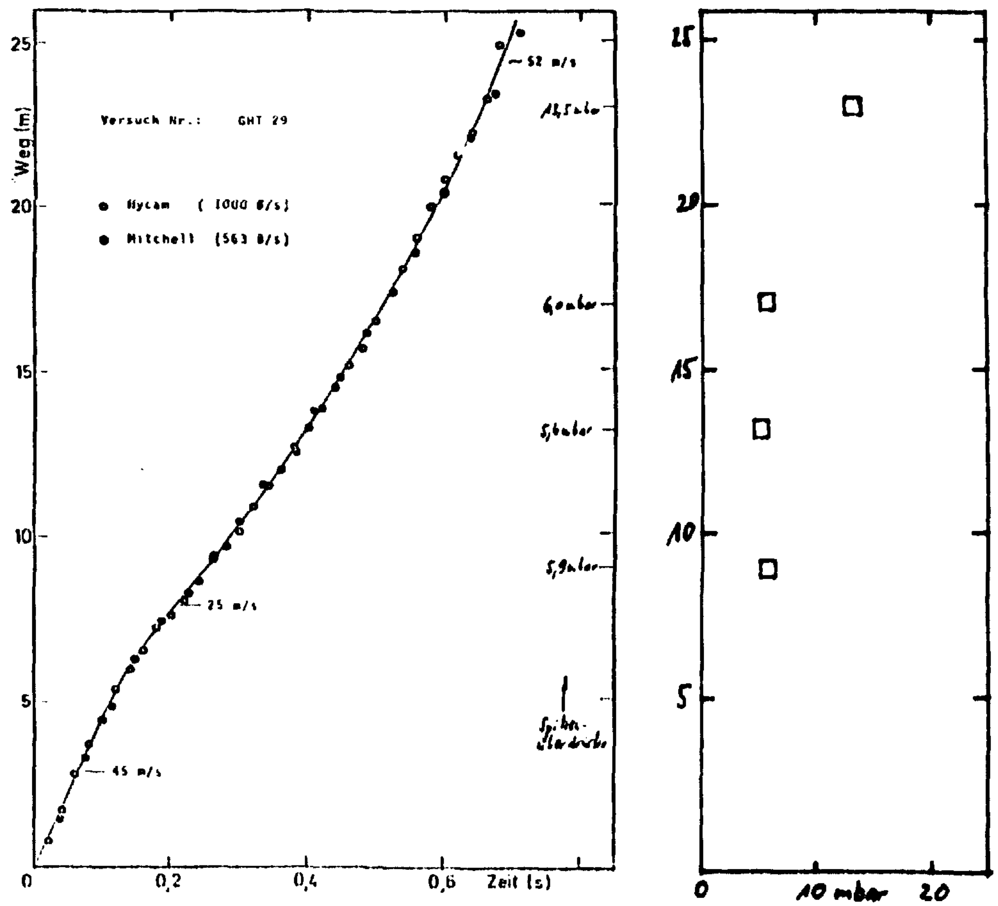


Fig. 11: Ignition of a hydrogen-air-mixture in a foil hose
Lower part: Position of flame front versus time.
Upper part: Measured pressure at different positions.

- the ignition of a nearly unconfined cloud by means of a nearly isochoric explosion (that means an explosion in a closed room) in order to generate a blast wave supported by burning;

- the ignition of a truly unconfined cloud generated by a bursting gas bottle.

Expecially the experiments concerning flame supported blast waves are of crucial interest for our question; they base on similar experiments of Wagner et al. / 7 / in laboratory scale, and of large-scale experiments performed in Norway / 8/.

4. Damage analysis

As mentioned above, the explosion hazard of gas explosion cannot be analysed in a satisfying manner, because the underlying damage-pressure-relationship is derived from TNT explosions. The different pulse shape of a deflagration, especially the high momentum related to the peak overpressure and the significant suction phase, may cause different destroying effects. It is to prove, whether the damage of large accidents can be explained by the pressure wave from a deflagration.

In order to know the damage of a blast wave, it is necessary to determine

- the load function by gas dynamical considerations and
- the behaviour of structures by structual dynamical methods.

4.1 Load function

Up to know, only the load function from a detonation shock wave has been known. Different from a shock, a deflagrative blast is characterized by a slow increase of pressure and flow velocity in front of the flame front. In order to calculate the reflection of this wave type, the slow increase is mathamatically modelled by a sum of subsequent small shocks. Fig. 12 shows the resulting load function supposing the very high flame front velocity U_F as indicated in the figures; the position of the rectangular building is inside the explosive cloud.

The load function is not only to be determined for broad structures like panes and walls, but also for slim struktures like stacks and pylons, for in the Flixbourough desaster some pylons showed a typical damage pattern. The analysis of damaged slim structures would have the advantage to show the effect of the flow component of the combined flow and pressure field of an explosion; in a first approximation, slim structures are destroyed by the dynamic pressure (times an adequate drag coefficient c_D), while plain and broad structures are loaded by the static pressure. The necessary drag coefficient c_D in the instationary flow field of a deflagration is going to be measured by a baloon explosion.

4.2 Structural behaviour

In order to analyse actual damage, the behaviour of panes, of brick and concrete walls as well as of pylons is to be investigated.

The work started with panes because a simple behaviour was expected. For the experimental work a simulator of the deflagrative pulse shape was developed (Fig. 13). The experiments with panes displayed large deviations caused by material properties and by the mode of fastening the panes in a frame, but we succeeded in describing the structural dynamics of panes mathematically (Fig. 14).

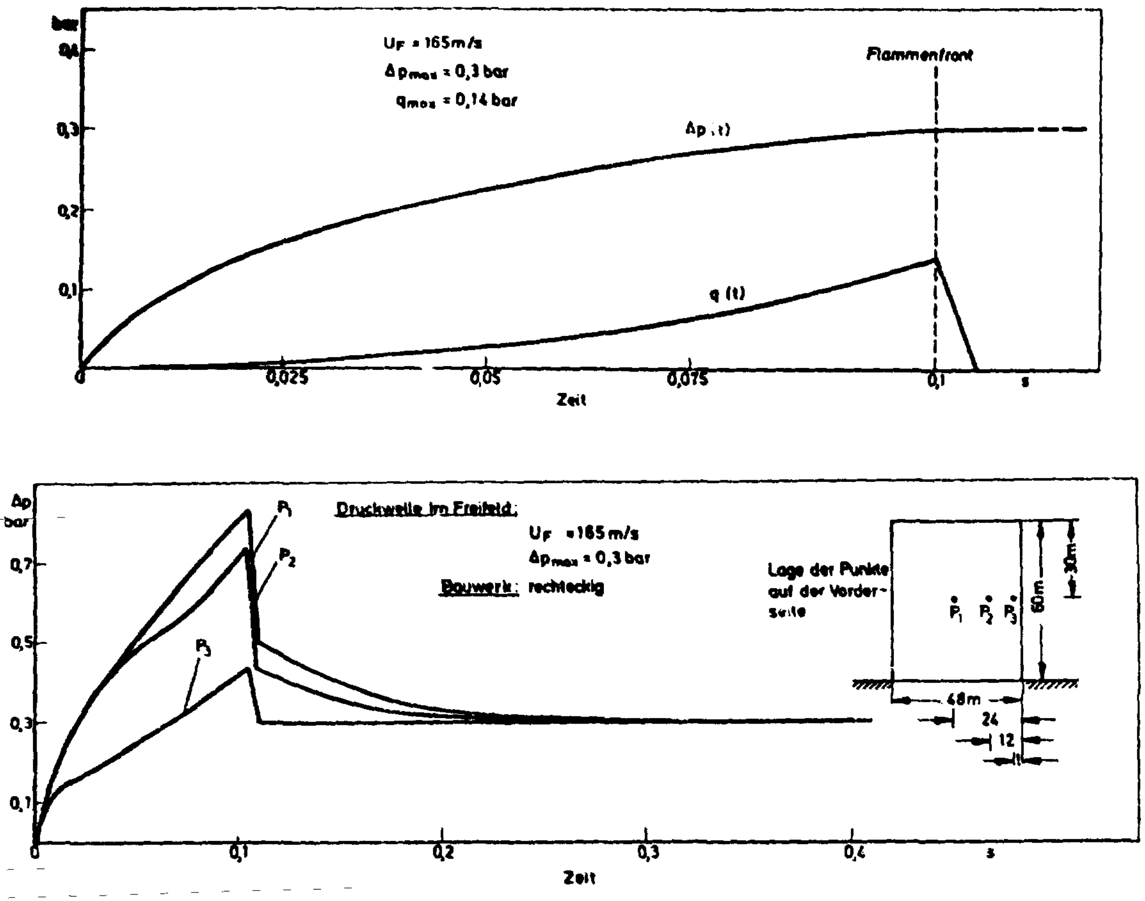


Fig. 12: Left: Static pressure Δp and dynamic pressure $q = \rho \cdot u^2/2$ as a function of time t; undisturbed deflagration (free field) distance from ignition point 25 m.

Right: Pressure load at 3 points of the front side of a rectangular building as a function of time.

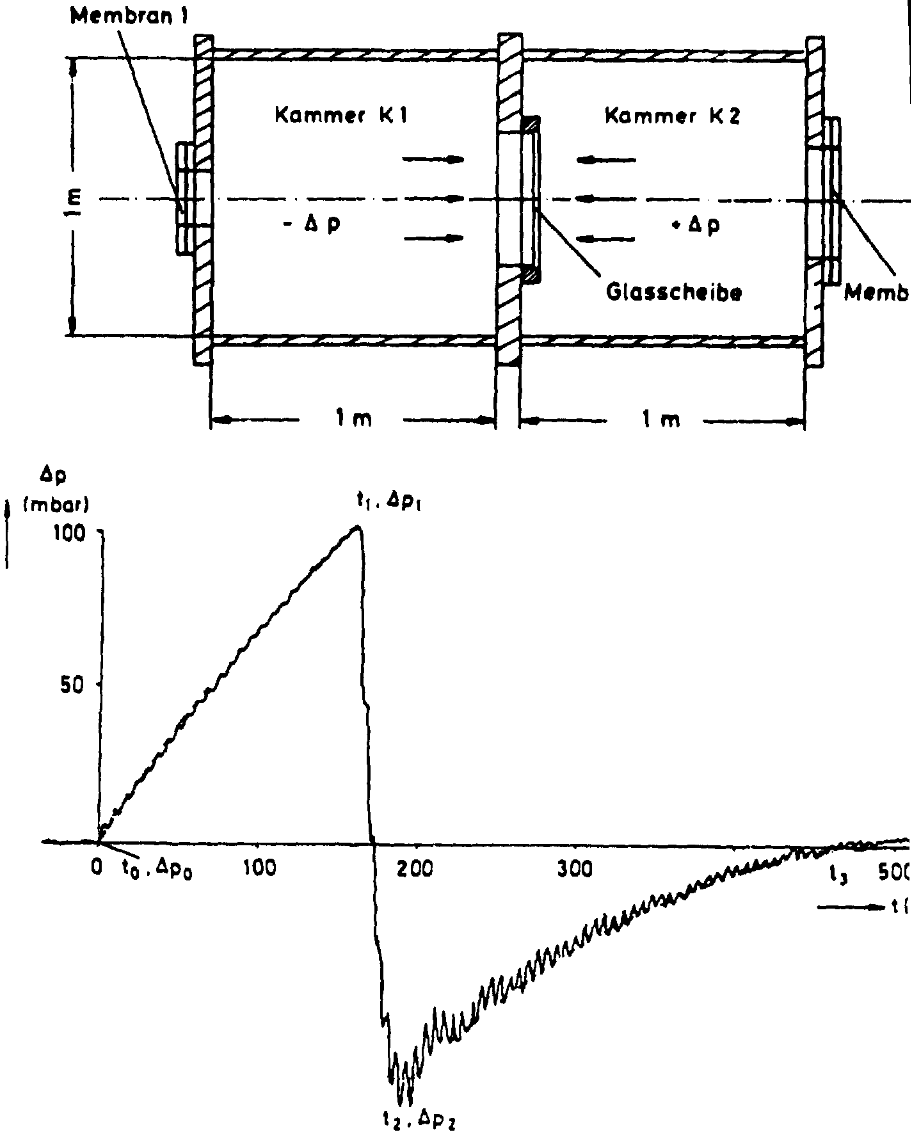


Fig. 13: Deflagrative pulse shape simulator and achieved pulse shape

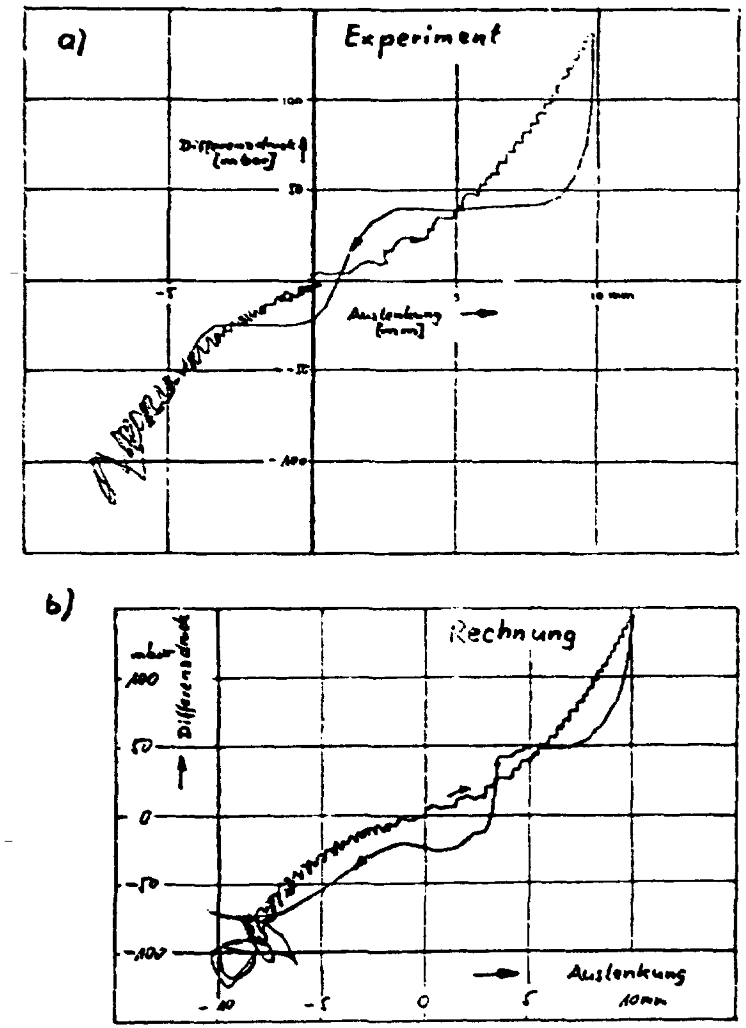


Fig. 14: Plot of overpressure versus displacement (in the middle of the pane) a) measured b) calculated

For the time being, the maximum stress is being calculated, which is caused by deflagrative and detonative pulse shapes: fig. 15 shows some plots for different peak overpressures and different durations of positive overpressure.

The medium stress (beyond which 50% of the panes are broken) was experimentally determined to about 750 bar.

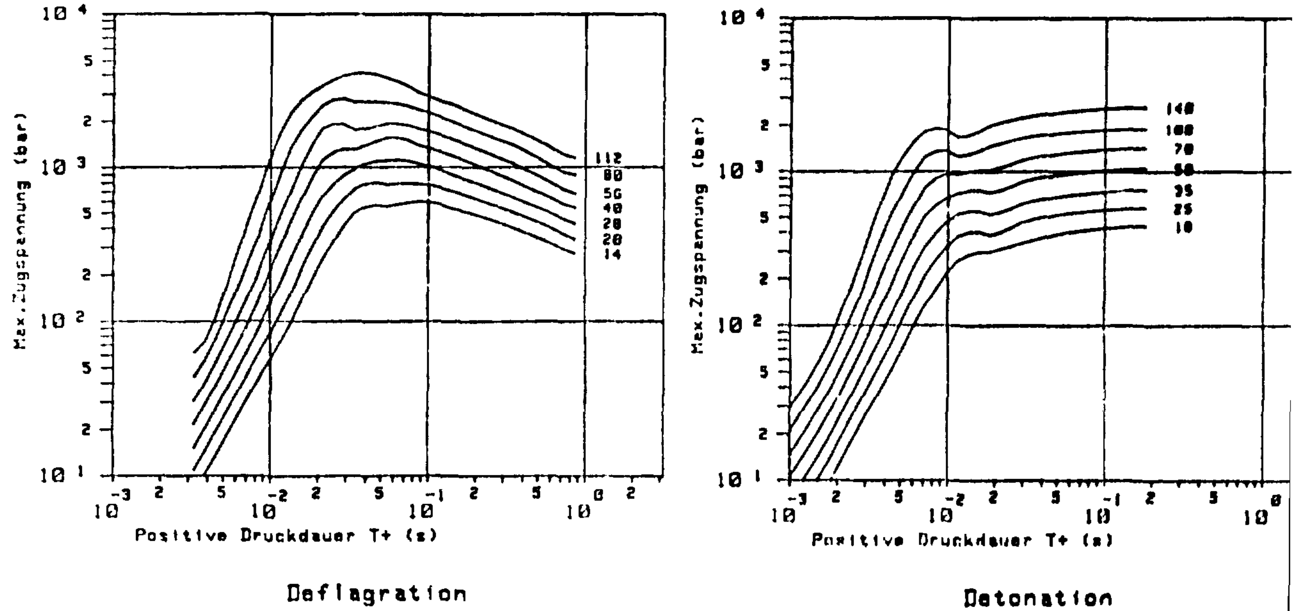
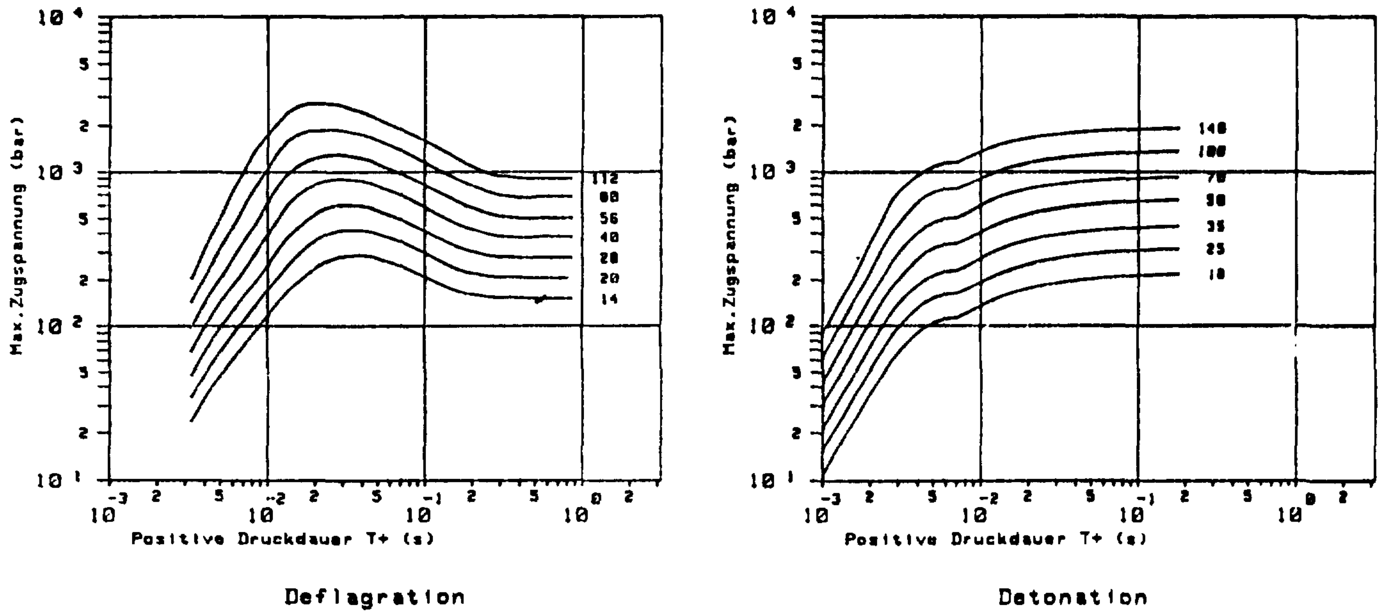


Fig. 15: Maximum tensile stress in a pane as function of duration of positive overpressure; the different graphs are calculated for different peak overpressure (in mbar); left part: deflagration, right part: detonation

a) Glass pane 1 x 1 m, 2.8 mm thick



b) Glass pane 0.5 x 0.5 m, 2.8 mm thick

The minimum peak overpressure to cause this tensile stress in a large pane is 20 mbar in the case of deflagrative pulse shape, whereas 35 mbar are necessary in the case of detonative blast waves. (For small panes the values are 35 mbar and 60 mbar, respectively.)

Furthermore, computer codes for concrete and brick walls are prepared. (The brick wall codes will be verified by measurements in the deflagration wave simulator.) By that, the different effects of the detonative and the deflagrative pressure waves can be compared. Some damage patterns of real explosion accidents will be analysed by means of these diagramms.

5. Conclusions

The programme comprises efforts in several scientific disciplines. For a reliable description of realistic gas cloud explosions in an industrial environment, the various results must be combined. It is expected that gas explosion accidents will be more correctly interpreted in this way than by the TNT equivalent. The final goal is to provide a representative pressure-time-function or a set of such functions. These functions should be the basis for safe design and construction of the nuclear reactor system of a coal gasification plant.

Since some crucial experiments, such as flame supported blast wave and burning vortices experiments, are still outstanding, no final conclusions can be drawn for the time being.

On the other hand, no result yet achieved contradicts the assumption that released process gas is only able to deflagrate; even in the case of hydrogen clouds within some confinement, deflagration is the only possible explosion process.

As an undisturbed deflagratation can only generate pressures significantly below 100 mbar, it should be possible to demonstrate that, if unfavourable configurations are avoided, a design pressure of 300 mbar is sufficient to withstand an explosion of process gas; this pressure should never be exceeded by process gas explosions irrespective of gas mass released and distance to release point, except possibly in relatively small areas.

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