

## **Gas Turbines - Continuous Trend Towards Higher Performance - The Insurance Aspects**

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### **Executive Summary**

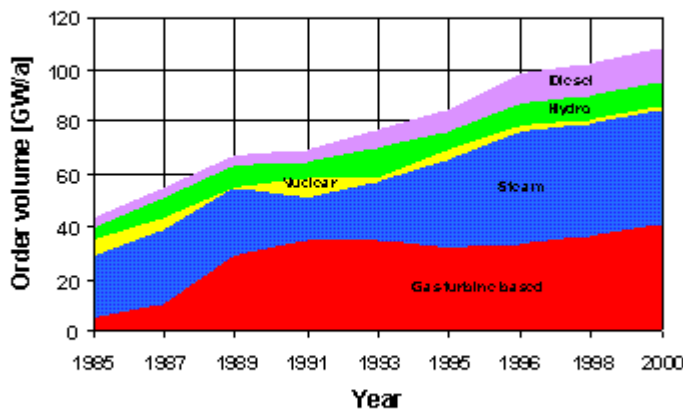
The paper gives an overview of the gas turbine power plant market and the gas turbine development, which goes into details of technology for optimisation of cycle performance, aerodynamics, output, combustion and fuel application.

The statistics illustrate the development on the insurance side, and some essential underwriting considerations are drawn from the technical development and insurance statistics.

### **Introduction and Market Situation**

Over the current decade, modern combined cycle power plants have been established as basic technology in the electric power production business (see figure 1). The success of the gas turbine technology is based on the low installation and maintenance costs, short installation time and the ecological advantages. Driven by the ongoing trends towards privatisation, stable fuel prices and the introduction of new cycles, enlarging the fuel spectrum towards heavy liquids and even solids (i.e. IGCC), gas turbine based power plants will hold or even increase its portion of the future power plants (see figure 2). Nevertheless the market to date is characterised by heavy competition between manufacturers, developers and insurers.

## Power Generation: Order Volume by Technology



Source: ABB

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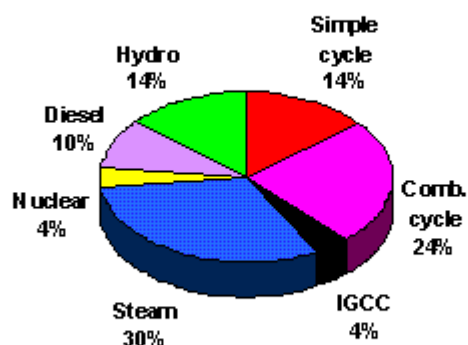
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The aim of this paper is to describe the present market and technology trends, to reanalyse the risk potential on the basis of failure statistics and to review underwriting considerations for the insurance industry.

Four technology consortia are sharing the market for stationary gas turbines. Besides smaller fluctuations, the market share distribution kept basically constant over the last decade. While GE and its licensee partners hold a major share of 40 to 50 %, the other competitors: Westinghouse/MHI, ABB and Siemens are sharing the rest at equal portions. To date the market of gas turbine developers and manufacturers is probably coming into motion due to the intended taking over of Westinghouse by Siemens and the review of the formation of GEC-Alstom. To what extent these trends will result in a change in overcapacities and competition is not yet clear.

## Power Generation: Technology Mix 2006



Source: GE

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The current competitive market can easily be illustrated on the basis of the installation prices. The

market price for combined power plants dropped from app. 800 \$/kW in 1990 to app. 450 \$/kW in 1998.

One major motivation behind this development can be identified by the trend to open the local energy markets to private investors and operators. Since 1994 an increasing part of the power business orders has been received from Independent Power Producers (IPP's). Success factors of these project organisations with their high amount of outside financing, is the application of advanced, highly efficient technologies and the wide protection measures and covers required from the manufacturers and the insurance industry.

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## Technology Development

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As summarised in figure 3, the basic strategy of the gas turbine manufacturers in this highly commercial environment is the permanent advancement of their technologies. Development goals to date are:

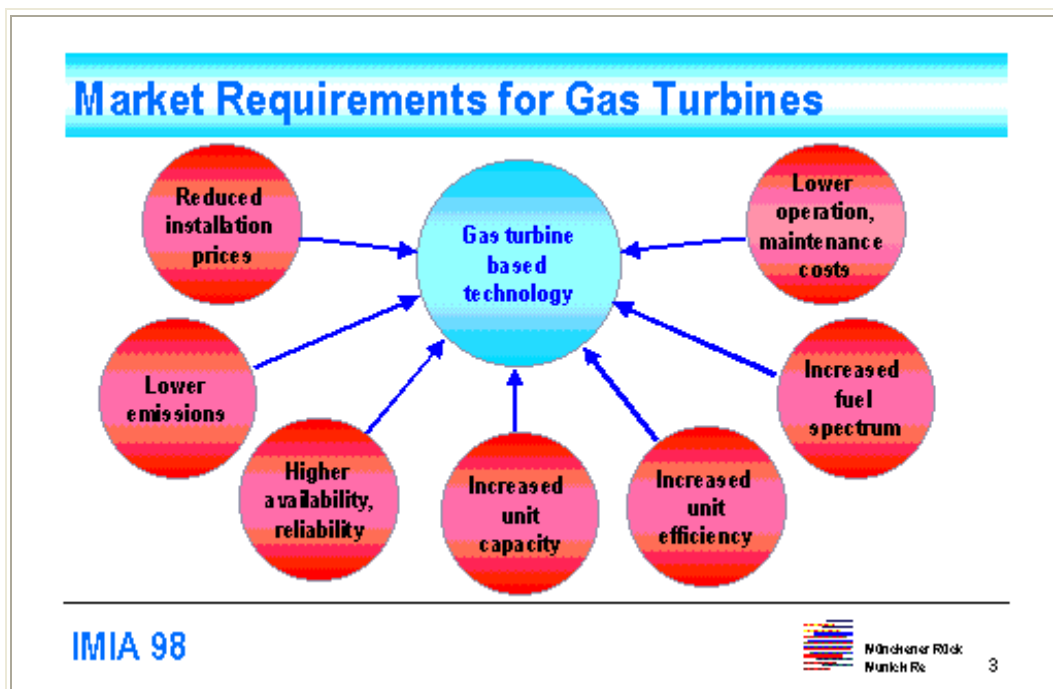
Reduced installation prices, increased unit capacity /Capital costs.

Increased unit efficiency, lower maintenance costs /Operation costs higher availability, higher reliability

Lower emissions /Operational licensing precondition in view of more stringent emission regulations

Increased fuel spectrum /New markets

Some of the measures used to reach these goals are in conflict to each other, see figure 4 and details below.



## 1. Cycle Optimisation

The basic way to increase the performance of gas turbines is raising the cycle parameters. By adding fuel to the combustion system, the average combustion and turbine inlet temperature is increased, which leads according to thermodynamic rules to a higher specific output and to better fuel efficiency of the gas turbine. To realise the increased cycle temperature, the components concerned, combustor and turbine, have to be basically redesigned using new, highly sophisticated technologies. If the turbine inlet temperature increases, also the operation pressure has to be increased to optimise the efficiency of the entire gas turbine cycle. Again new compressor designs with more stages and increased aerodynamic load will be used.

The turbine inlet temperature is the major parameter to describe the technology status of a gas turbine and therefore often used for technology comparison. State of the art stationary gas turbines operate at turbine inlet temperatures of 1350 °C (using Mitsubishi's definition, i.e. measurement point is the entrance of stator vane 1. Other gas turbine manufacturers are using individual definitions: GE and Westinghouse state the firing temperature measured before turbine rotor blade 1, while Siemens and ABB are using an average turbine temperature according ISO2314). As shown in figure 5, the different definitions lead for gas turbines with comparable performance (and turbine inlet temperatures) to significant differences in the officially stated cycle temperatures. The new models, being available soon, will operate with gas temperatures of 1500 °C at the turbine inlet.

Gas Turbine Models, 50 Hz, $P_{el} > 200$ MW						
Manufacturer	ABB	Siemens	GE	W/MHI	GE	W/MHI
Model	KA 26	GuD V94.3A	S109FA	MPC P1 701F	S109H	MPC P 701G
Rating-class	F	F	F	F	GH	GH
1st unit available	1996	1995	1994	1992	2000?	1998
Net CC-output	396	380	391	399	490	484
Gas turbine output	257	255	254	266	n. available	329
Net CC-efficiency	58.5	58	58.7	58.9	60	58
Turbine inlet temperature*						
ISO*	1225	1200				
firing, before blade 1*			1327		1400	
before vane 1*				1407		1500
Pressure	30/15	16	15.4	16	23	21
Combustor type	2'annular	1'annular	1'can annular	1'can annular	1'can annular	1'can annular
Special	Reheat				Steam cooled	Steam cooled

Remark: gas-cool fuel, standard Combined Cycle configuration, 600-steps  
 \* Manufacturers are using different definitions for the turbine inlet temperature

Source: Gas Turbine World

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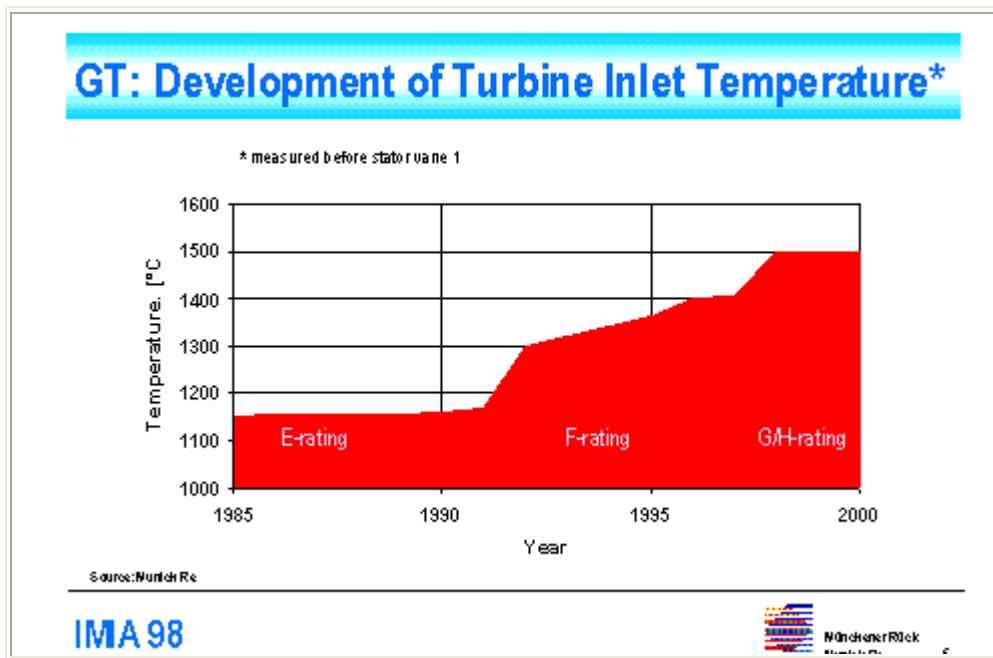
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The traditional restriction of the turbine inlet temperature is set by the mechanical and chemical strength of the hot gas path components, especially the first turbine stage. In the 80ies and early 90ies technical improvements were concentrating on gradual improvement of the cooling technology. The cycle parameters accordingly had a smooth development. With the introduction of a new generation of gas turbines, the so called F-technology since the beginning of the early 90ies, the turbine inlet temperature could be dramatically increased by the use of technologies derived from the aero-engines. On the basis of directionally solidified (DS) or single crystal (SC) materials in connection with advanced air cooling schemes and corrosion and thermal barrier coatings (TBC) further steps of the average combustion temperature were made possible.

The maximised turbine inlet temperature was also coming along with a development towards the

installation of annular combustors. Siemens with the 3A-family and ABB with the GT13E2 swapped from their traditional silo combustors designs towards modern, compact annular combustors. Thereby an even circumferential turbine inlet temperature profile and minimal cooling areas at the combustor walls could be achieved.

As from 1998, the first power plants based on the next generation of gas turbines, the so called G-technologies, with turbine inlet temperatures measured before vane 1 of up to 1500 °C and pressures up to 21 bars are being sold (see figures 5 and 6, MHI701G, W501G). To reduce the amount of cooling air and to keep the nitrogen oxide emissions (NO<sub>x</sub>) at a tolerable level, the traditional air cooling of the combustion chamber has to be replaced by a revolutionary steam cooling.



At the same time the H-rating, using this revolutionary new cooling methods even for the turbine stator and rotor, is announced to be available for the early year 2000 (GE5001H, GE7001H). The cooling medium steam will be supplied externally from the steam cycle of the CCGT. For start up, part load and redundancy purposes an auxiliary steam boiler may be necessary. The replacement of air as cooling medium by steam leads on the one hand to a further optimisation due to the fact, that all of the compressed air can then participate in the high temperature cycle of the gas turbine as air is no longer derouted for cooling. On the other hand the new technology opens a wide risk potential like design uncertainties, steam quantity as well as quality plus additional requirement of hardware and control equipment.

As a special development, ABB established with the GT24/26-family a reheat process, well known from steam turbines, into the gas turbine. By increase of the pressure ratio to 30 and adding a second combustor after the high pressure turbine a "carnotisation" was achieved. The improved process leads as well to efficiency, specific output and emission advantages as to increased complexity (i.e. compressor with increased number of stages, higher compressed air temperatures and second stage combustion) however at lower cycle inlet temperatures.

## 2. Optimised Aerodynamics

A further measure to increase the gas turbine performance is given by the optimisation of the aerodynamics. With the introduction of advanced design and calculation tools like CAD and CFD further steps in the minimisation of gas flow losses were made possible. As examples three development tendencies are described below:

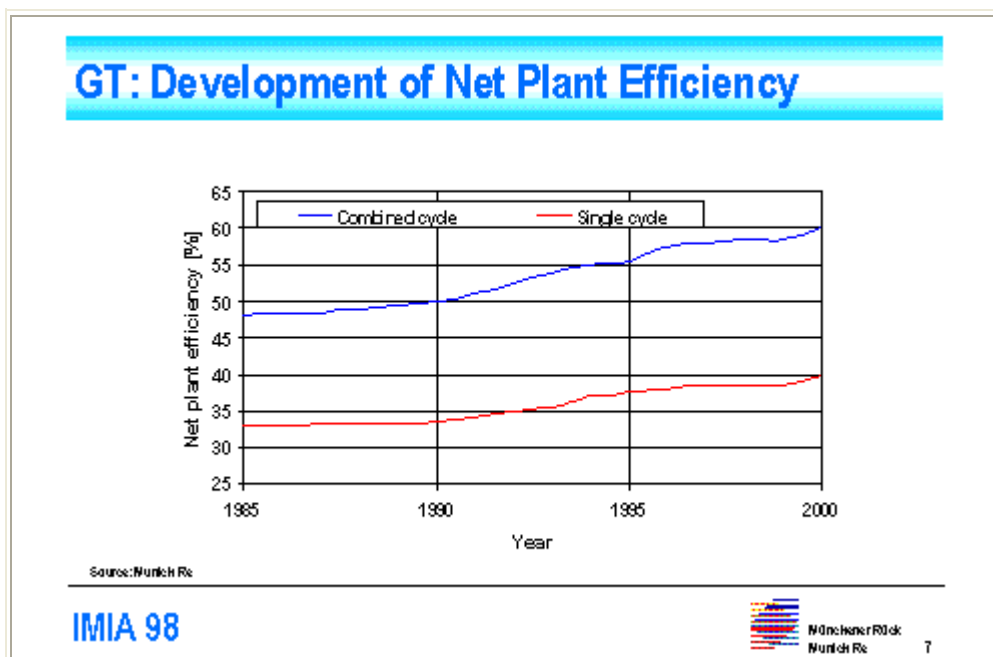
Although the pressure ratio of the gas turbines was raised, the number of compressor stages could be kept constant or even reduced by the introduction of higher loaded airfoils (sub- to transonic profiles). These however will be more sensitive regarding deviations of the optimal operation mode.

The secondary flow losses of the turbine blading is also being further minimised by moving from the 2-dimensional towards the 3-dimensional bladings. With the introduction of steam cooled gas turbine vanes and blades a further reduction of the primary flow losses will be possible. Both developments may lead, in combination with the advanced new materials and manufacturing methods, to dramatically increased sensitivity, delivery times and costs of the new turbine vanes and blades.

The overall performance is heavily influenced by the quality of the sealing. Therefore one development goal is the minimisation of leakages between the vanes and the rotor as well as between the blades and the stator. Highly sophisticated calculation methods and designs, which allow an exact prediction of the relative movements between rotor and stator at all operational conditions at all locations are being used for a further reduction of the sealing distances. Smallest mistakes in the design process or deviations in the operation condition can lead to contact between rotor and stator and consequently to damage and losses.

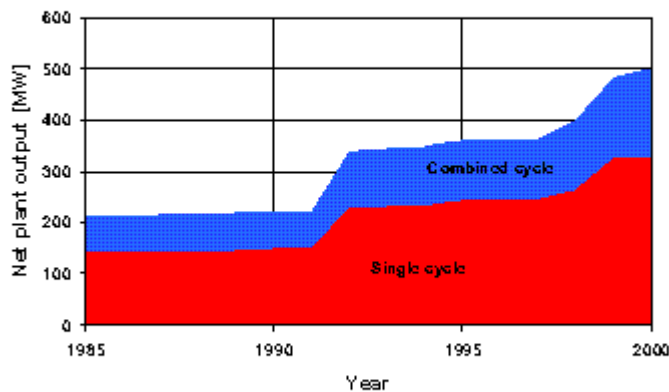
### 3. Performance Overview

As a result of the improvements, described above, the gas turbine efficiency and output could be dramatically increased during the period 1990 to 2000. Figure 7 demonstrates, that single cycle efficiencies will increase from 33 % up to 40 %. Combined cycle power plants, where the remaining thermal energy of the gas turbine exhaust gases is used to operate a heat recovery steam generator with an adapted optimised steam turbine cycle, starting from 50% in 1990, soon reach the 60 % margin. At the same time the gas turbine capacity is more than doubled from 150 MW up to 320 MW.



The 50 Hz combined cycle standard unit in the year 2000 will reach 500 MW, gas turbine, steam turbine and generator installed as a single shaft unit (see figure 8).

## GT: Development of Net Plant Output, 50 Hz



Source: Munich Re

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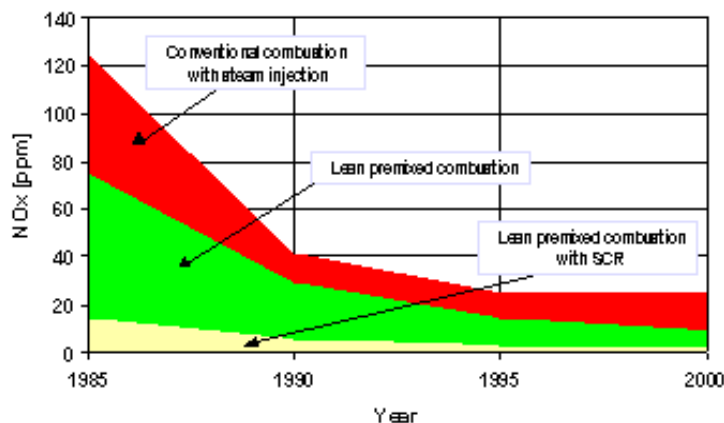
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### 4. Combustion Systems

At the same period, when the efficiency and thereby the operation costs of the gas turbines could be clearly improved, a strong demand to reduced emissions was coming up. Especially in the USA, with its regulations like the BACT the licence for operation was and is made dependent on the installation of the Best Available Control Technology. In our days the ecological impact of a new project is a major argument for project decisions all over the world.

As an example for the development of gas turbine emissions the typical Nitrogen Oxide values (NO<sub>x</sub>) in the exhaust gases are shown in figure 9. Nitrogen Oxides are basically produced, if the nitrogen and the oxygen of the atmosphere are reacting with each other. This process is depending on reaction time, pressure and mainly the temperature in the flame. The production of "thermal NO<sub>x</sub>" starts typically at temperatures above 1500 °C and shows an exponential dependency to the temperature.

## GT: Development of Nitrogen Oxide-Emissions



Source: ABB

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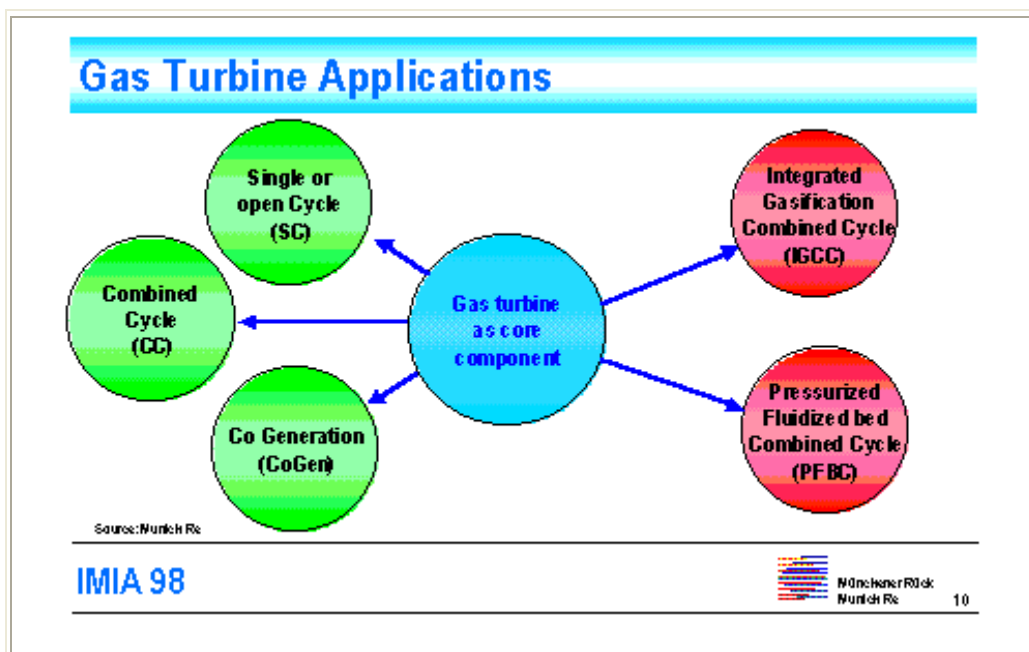
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The combustors working with diffusion type of flames, which have been reliably operating for decades in stationary gas turbines and jet engines, are producing local flame temperatures of above 2000 °C and primary NO<sub>x</sub>-values of several hundred ppm. While secondary measures like the installation of special catalysts (SCR) for NO<sub>x</sub>-removal or the reduction of flame temperatures by the injection of water or steam have led to reduced plant efficiency and additional installation and operation costs, the introduction of premix combustors in the mid 80ies demonstrated the potential to dramatically reduce emissions without influencing the efficiency. The idea behind is the prevention of temperature peaks of more than 1500 °C in the flame. Therefore in a first step the fuel has to be homogeneously mixed with almost all of the combustion air and then in a second step, locally isolated, the reaction has to be made possible at homogeneous temperatures in the region of 1500 °C. The critical items are avoidance of pre-ignition and combustion instability. Both do happen at frequent times today and have led to severe damage /5/. The realisation of premix combustion led typically to more and smaller burners with complicated flow fields and staged fuel injection as well as highly sophisticated control technologies. While the manufacturers have not yet solved these problems satisfactorily on the current gas turbine types, new challenging demands are formulated. The upcoming generation of gas turbines will operate on turbine inlet temperatures of 1500 °C, meaning that the average flame temperature and turbine inlet temperature will differ insignificantly. Therefore the conventional combustor cooling (convective + film cooling), where a remarkable portion of the compressed air is used to cool down the combustor wall and to dilute the combustion gases, have to be replaced by pure convective (ABBGT26) or steam cooling (GE7001H, MHI501G) or the use of "uncooled" ceramic materials (Siemens V94.2A). Again a trend to higher complexity and smaller safety margins can be expected.

While the described premix combustion systems were typically only able to operate on a narrow band of gaseous fuels, now the first oil premix systems adapted to earlier gas turbine types with lower ratings are coming into the market. There the additional difficulty is to evaporate the fuel before mixing and reaction can take place. Aggravating circumstances are the shorter ignition delay times of the liquid fuel compared to gas. Nevertheless development is going into that direction also for the present types (ABB GTX100).

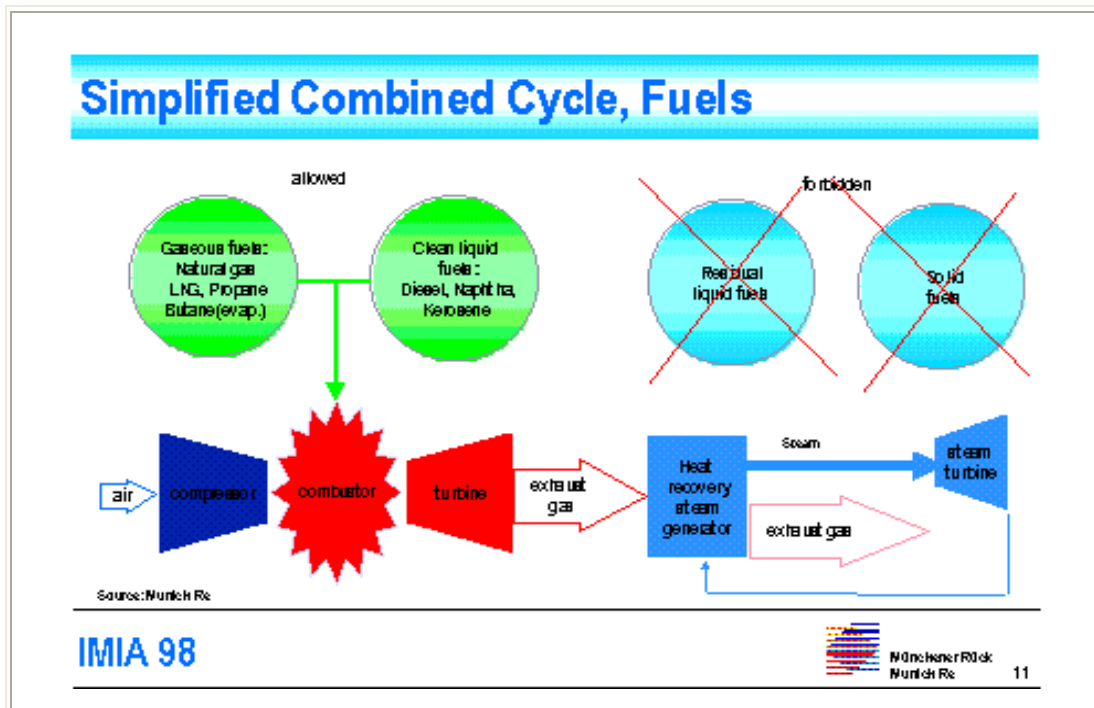
## 5. Gas Turbine Applications and Fuels

Besides the traditional applications of gas turbines as peak load devices in simple cycle installations and as medium or base load applications in combined cycle and cogeneration, new arrangements summarised in figure 10 are entering the market as prototypes but in commercial operation. The idea behind is connected to make available the impressive achievements of the gas turbines regarding efficiency, ecological and price advantages also for a wide range of fuels.





Up to now it was only possible to operate gas turbines with relatively clean fuels like natural gases or light oils. Heavy liquids, waste fuels or solids (coal), which are available in a lot of countries like India, China or the USA at very competitive prices couldn't be burnt in gas turbine combustors, due to problems with emissions, erosion or corrosion of the hot path parts (see figure 11). To make these cheap fuels available for the high efficient combined cycle, additional fuel preparation, combustion and hot gas cleaning processes were designed and tested over the last decade. In our days, the step towards commercial competitiveness seems to be reached and for the future an increasing market share is predicted (compare fig. 2).

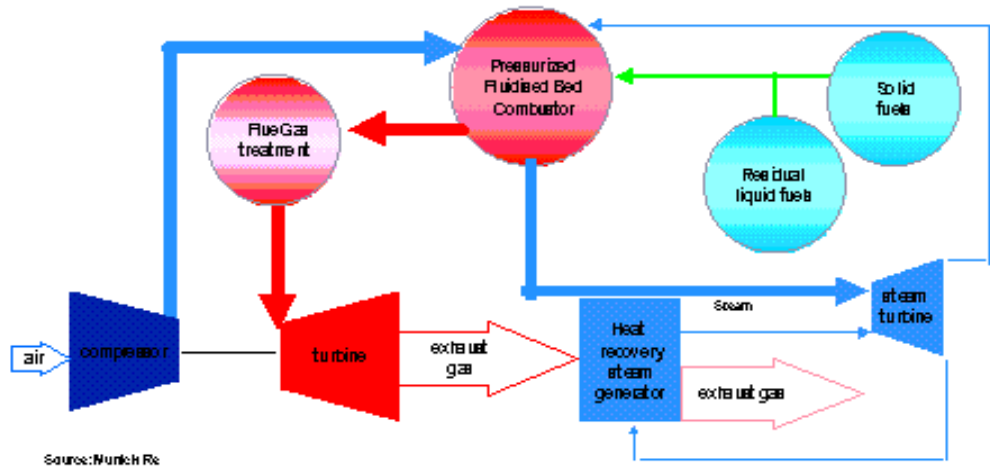


The Pressurised Fluidised Bed Combined Cycle concept (PFBC, see figure 12) has demonstrated its commercial and technological potential to improve the economical and ecological situation of coal as energy source for the coming years.

Compressed air of the gas turbine compressor charges air to the pressurised fluidised bed boiler, where the coal is burnt directly and the majority of the steam for the steam turbine is produced. The exhaust gases of the boiler are cleaned from sulphur and dust before they re-enter the gas turbine for expansion.

The major question regarding the reliability of the whole cycle is the quantity of dust entering the gas turbine. Series of cyclone or ceramic filters are used to ensure acceptable gas purity and thereby to avoid fast erosion or deposit built-up on the hot gas parts. Especially the air cooling concepts of modern gas turbines with their tiny cooling holes are not tolerating any dust contamination of the hot gases. Because of the technical restrictions in filtration of the deposits out of the boiler's exhaust gases, the turbine inlet temperature has to be reduced to values, where uncooled or slightly convective cooled vanes and blades are usable (app. 850 °C). In combination with the totally unique arrangement of the gas turbine, the PFBC-boiler with the huge cold and hot gas pipes replaces the original gas turbine combustor, a new gas turbine design, optimised for the cycle is necessary. Due to the moderate turbine inlet temperature and the high amount of energy which is transferred to electricity directly in an ordinary steam process, the cycle potential regarding efficiency is still nearer to the simple steam turbine cycle than to the combined cycle. A major advantage compared to the simple steam cycle is connected to the increased compactness coming along with the high operation pressure of the boiler.

## Simplified PFBC, Fuels



Source: Munch R&E

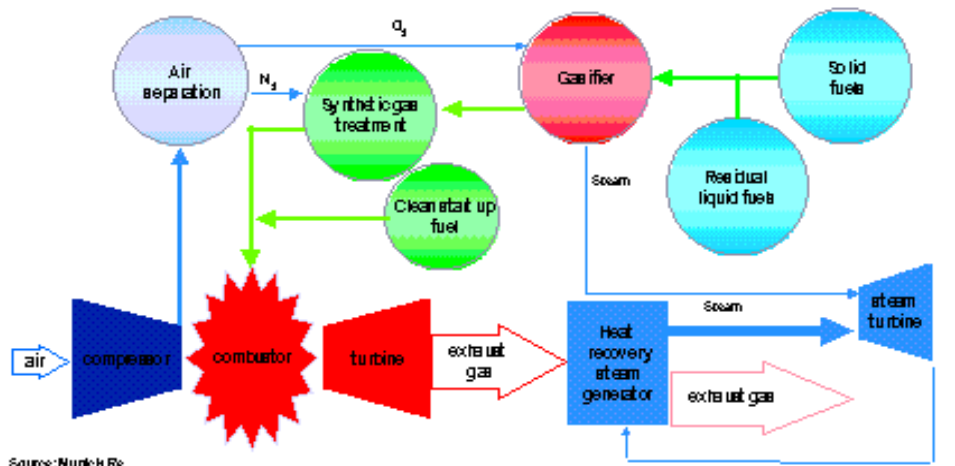
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The Integrated coal Gasification Combined Cycle (IGCC, see figure 13) is basically similar to the combined cycle but extended by an additional gasification device. The fuel, for example coal mixed with petroleum coke, is fed into a gasifier vessel and there gasified at pressures and temperatures of typically 25-30 bars and up to 1600 °C by addition of pure oxygen and steam. Carbon conversion rates of more than 99% are achievable. The hot gases from the gasifier are cooled down to temperatures of app. 250 °C, dedusted, sulphur is removed and after mixing with the nitrogen from the air separation process the synthetic gas with a medium caloric value containing respectable amounts of CO, H<sub>2</sub> and N<sub>2</sub> is fed into the gas turbine combustor. The oxygen is prepared at an air separation unit, being fed by air from the gas turbine compressor.

To realise this highly integrated cycle in an optimal way, the standard gas turbines have to be modified. The extraction of air has to be made possible by additional connection flanges. The flow and energy balance of the compressor, combustor, turbine and generator has to be adjusted to handle the air separation, the heavily increased fuel mass flows and the increased electrical output of the integrated gas turbine. Finally the fuel characteristic and operational conditions ask for new burners, a separate fuel for start up and redundancy reasons and a highly sophisticated control technology of the overall system.

## Simplified IGCC, Fuels



Source: Munich Re

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## 6. Other Trends

To optimise the economic situation further, additional trends in the development of gas turbine power plants are common:

### *Reduction of parts*

I.e. new airfoils make it possible to reduce the number of turbine vanes and blades thereby cutting costs.

### *Single shaft arrangements*

Instead of the traditional arrangement, where a combined cycle consists of one gas turbo set incl. generator and one separated steam turbo set with its own generator, the single shaft arrangement combines one gas turbine, one steam turbine and one common generator on one rotor line. Often the steam turbine is prepared to be switched on and off during operation by the addition of a self shifting and synchronising clutch. In such a configuration, commissioning and operation of the gas turbine is possible even if the steam cycle is not yet available.

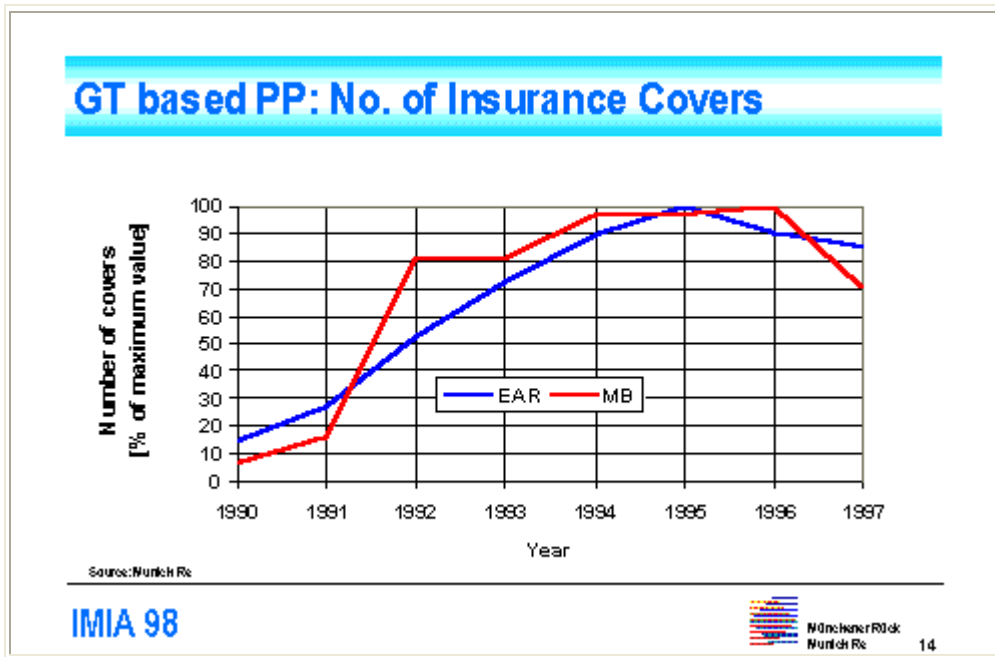
### *Extended inspection and exchange intervals*

Improved design and control methods shall make it possible to cut operation and maintenance costs by increased inspection intervals. With their advanced know how most of the manufacturers are predicting increased life times for hot path components. How far these goals, which had been promised nearly for each new gas turbine generation before but which were seldom reached, will be successfully realised will be an interesting question for future MLOP-covers.

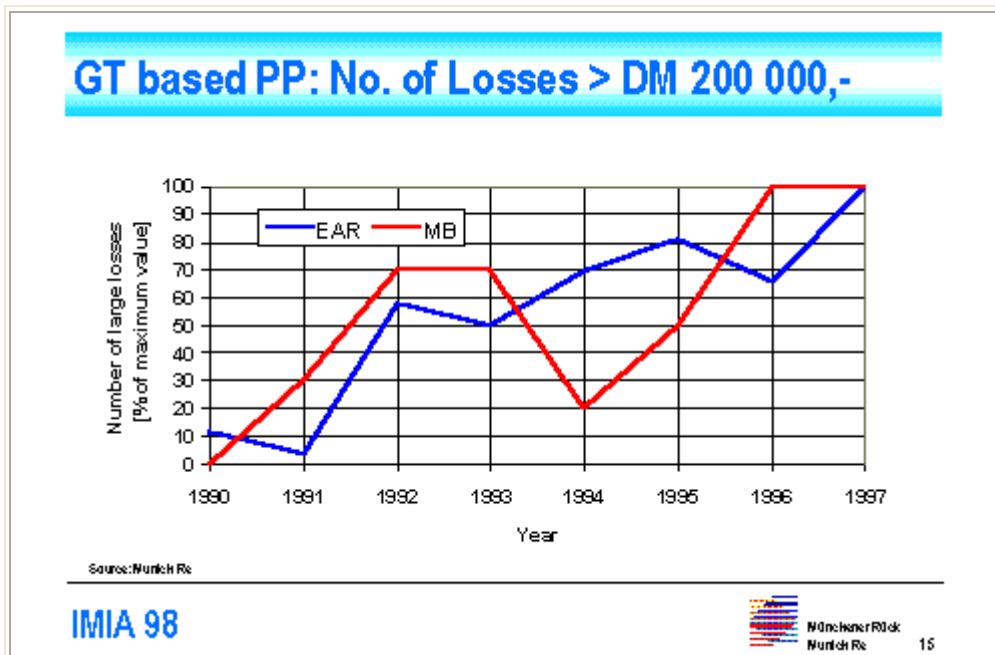
## Statistics

Following the trend in the order intake with a small delay time, the number and amount of insurance covers for gas turbine based power plants was increasing during the early 90ies (all statistical evaluations based on Munich Re risk records). This development stabilised in 1995 on a high level (see figure 14). According to the predicted increasing market share of gas turbine based power plants including IGCC, the ongoing success of the IPP-projects and the introduction of the new class of highly efficient gas turbines, we can assume an increased need for insurance capacity for the

next decade.



As described several times /1,2,3,4/ the last technology step, the introduction of the F-class gas turbines into the market in the context of a highly competitive environment, was followed by a remarkable series of big failures. Instead of installing proven technology, nearly each new power plant is being equipped with gas turbines, containing at least some new elements or features. The permanent pressure to deliver up-rated model versions within shortest time periods make it nearly impossible for the manufacturers to test the components sufficiently before delivery. The real operation experience has to be gained on site. Some of the extra costs have to be paid by the customer or the insurers. As shown in figure 15, starting in 1991 the number of EAR-losses increased, while the number of large MB-losses followed this trend with the natural delay. The top level there seems not to be reached yet.

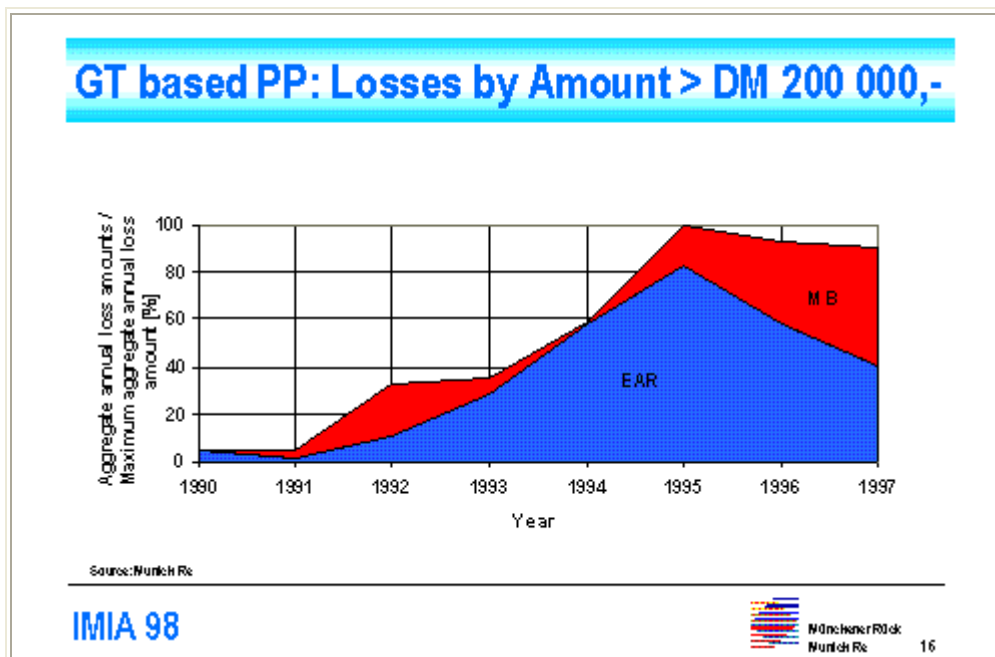


The influence of the cost and the technology race is even more clearly pointed out, looking to the total amount of losses in term of costs for risks recorded by Munich Re. As shown in figures 16 and 17, the sum of EAR and MB losses for gas turbine power plants was constantly increasing between 1991 and 1995 respectively 1997. The difference between diagrams 16 and 17 is the exclusion of the catastrophic "Leipzig" loss in 1995 in diagram 17 to point out the average trend more clearly. Still in 1997 the losses reached 15 times the value of 1991. During the same period, the newly installed electrical capacity and number of projects per year kept nearly constant, while the number of projects protected by insurance was increasing slowly.

Beside the market information, the available data material allows it to investigate the relevant reason for these failures. The highly interesting question, which components in combined cycle applications are responsible for most of the failures is answered in figure 18. There, based on 194 major losses, the gas turbine losses represent 78% of the total sum of the gas turbine based power plants failures in the 90ies. The gas turbine excluding generator represents typically 20 % - 25 % of the value of such a power plant.

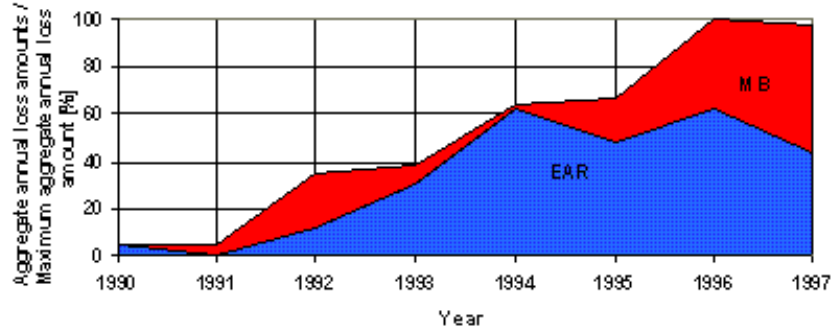
Looking into the components of gas turbine failures in detail, the turbine is responsible for 45 % of the total losses. It is clearly the element where the increased parameters of modern gas turbines with the high cycle temperatures have to be paid.

In figure 19 the same losses are analysed regarding the class of failure. As assumed earlier, the product failures represent with 65 % (24 % for design failures, 29 % for faulty material and manufacture and 12 % for faulty erection) the major share of the losses in the 90ies. All statistics are based on data material recorded with Munich Re and may deviate from the overall market situation or individual insurers.



## GT based PP: Losses by Amount > DM 200 000,-

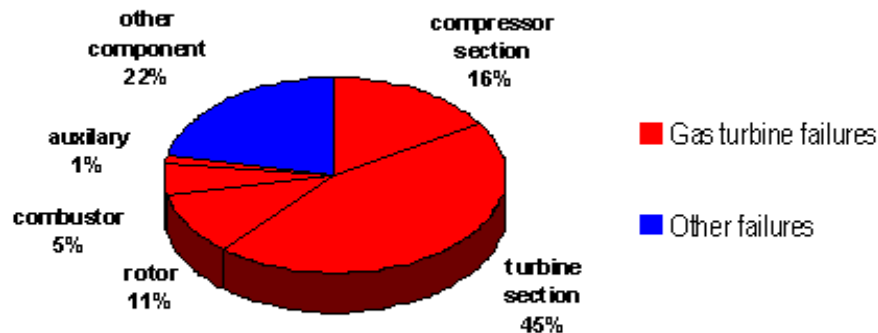
Excluding the catastrophic "Leipzig" loss in 1995



Source: Munich Re

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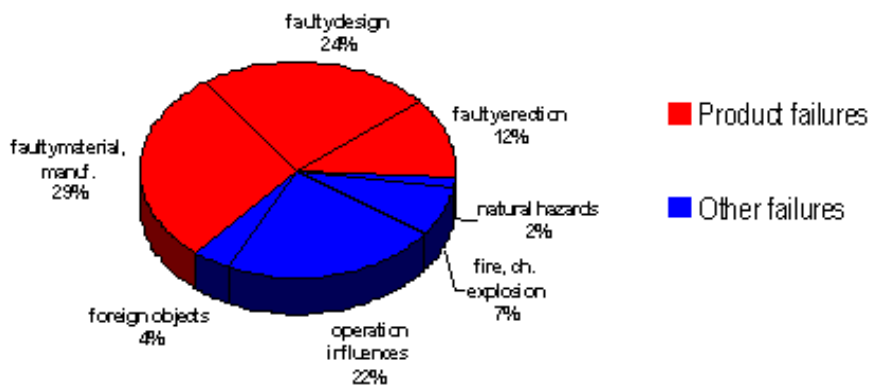
## GT based PP: Failure Sources by Components



Source: Munich Re

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## GT based PP: Failure Sources by Influences



Source: Munich Re

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### Underwriting Considerations and Conclusion

Based on the market and product development described above as well as on the loss experience of the last years, the following section will give some basic underwriting considerations regarding the gas turbine based power plants.

The demand for insurance protection as well as the related risks will further increase over the next years. Even in the current competitive situation, insurers should therefore always be aware of the chances and risks connected to the developments described above and follow some simple rules.

The level of rates has to be set at adequate level to cover at least the burning costs derived from statistical evaluation including a catastrophic loss reserve and insurance administration costs.

A most careful approach is needed with regard to the cover of maker's risk for models not satisfactorily proven. A gas turbine or modification is commonly judged as unproven as long as this type has not yet reached 8 000 hours of trouble-free operation. The underwriter has to check carefully, if the gas turbines will be operated under standard conditions, or if the project uses special fuels or improved new elements leading to increased efficiency.

If maker's risk is not fully excluded from the policy, the exclusion could be restricted to the unproven machine or modification. For any wider cover, if at all considered feasible, it is recommended to apply very high deductibles or coinsurance by the manufacturer with a reasonably high minimum deductible during testing and initial operation.

For the critical parts along the hot path, which need reinstatement or replacement at certain intervals, the machinery insurance cover should incorporate a clause, which in the event of a loss restricts liability to the unexpired life time of the components, i.e. depreciation shall be applied for the replacement components (see e.g. Munich Re end. 333).

### References

/1/ Industrial Gas Turbine Development And Operation Experience; IMIA 16-59(93)E

/2/ Bill Roberts; Power Project Insurance; HSB; June 25-27 1997

/3/ H. Huppmann et al; Large-scale Technology Risks A Challenge For Insurers and Reinsurers; The Geneva Papers on Risk and Insurance, 21 (No.80, July 1996),401-420

/4/ H. Weisser; Risikotechnische Beurteilung moderner Kombinations- und Verbundkraftwerke; Allianz Report 69 (1996) Heft 5

/5/ M.Valk et al; Moderne Vormischbrenner für Gasturbinen - Technologie und Probleme aus Sicht des Versicherers; VGB-Fachtagung 4.12.1997