Solar Hydrogen Project at Neunburg vorm Wald, Germany

SWB
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Safety concept of the Solar Hydrogen Demonstration Plant at Neunburg vorm Wald, Germany

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Summary

At the Neunburg vorm Wald solar hydrogen facility, the electrical energy of photovoltaically generated electricity is converted into chemical energy in the form of hydrogen, which is stored to be used subsequently for generation of power and heat. Concerning hydrogen, the facility contains three different types of water electrolyzers, catalytic and conventional advanced heating boilers, a catalytically heated absorption-type refigeration unit and three different fuel cell plants for stationary and mobile application.

The facility also comprises a outdoor filling station, at which various systems for fuelling vehicles with liquid hydrogen are undergoing testing, and a indoor filling station for compressed hydrogen. To counteract the hazards arising in connection with the storage and use of hydrogen, structural precautions were taken in construction of the plant systems and buildings and these are supplemented by appropriate monitoring and safety systems as well as operating procedures.

Introduction

By the year 2000, the shareholders of Solar-Wasserstoff-Bayern GmbH (SWB) - namely Bayernwerk (70 %), BMW, Linde and Siemens (10 % each) - will, with the aid of grants from the German Federal Research Ministry and the Bavarian State Economics Ministry, have invested about DM 140 million in the Neunburg vorm Wald demonstration project. In addition to photovoltaic power generation, plant systems required in future hydrogen-based energy supply are being tested on a scale oriented to industrial application (*Fig. 1*) .
Planning and design of the safety measures benefited from the shareholders' past experience in operation of electric power plants, chemical plants and cryogenic tank systems. These measures were defined in coordination with the technical inspection society and the

competent licensing authorities.

Safety prerequsites

The operating concept provides for the overall plant to be manned only on workdays, for a single shift during the period from November to February and two shifts in the months March to October. The plant is manned around the clock only when special test plans are conducted, as the initial arrangements made with the authorities thus far did not permit "unsupervised hydrogen operation". Increasing the sophistication of safety measurements made "unsupervised hydrogen operation" possible for a maximum period of 24 hours.
Given these conditions, most of the hydrogen components are installed inside a operating building for reasons of both security and frost protection. Outdoor installations are the liquid hydrogen filling station, the gas storage vessels, and the refrigeration system, which is an air conditioning unit modified for operation on hydrogen and designed exclusively for outdoor siting The electric forklift truck powered by fuel cell with hydride hydrogen storage is tested both outdoors and stationary in the operating building (*Fig. 2*).
It goes without saying that all pertinent engineering rules together with safety codes and explosion protection regulations applying to the chemical industry have been included in the safety concept during planning, design, installation and operation of the solar hydrogen plant. Full allowance has also been made for the safety-related properties of the gases and liquids handled within the solar hydrogen plant, such as natural gas, oxygen, hydrogen both gaseous and liquid, carbon monoxide, nitrogen and potassium hydroxide solution.

Solar hydrogen technology is accordingly being investigated in a demonstration project, that is closely simulating practical conditions and is unique in the world. The site plan of *Fig. 1* conveys an impression of the size and layout of the overall facility.

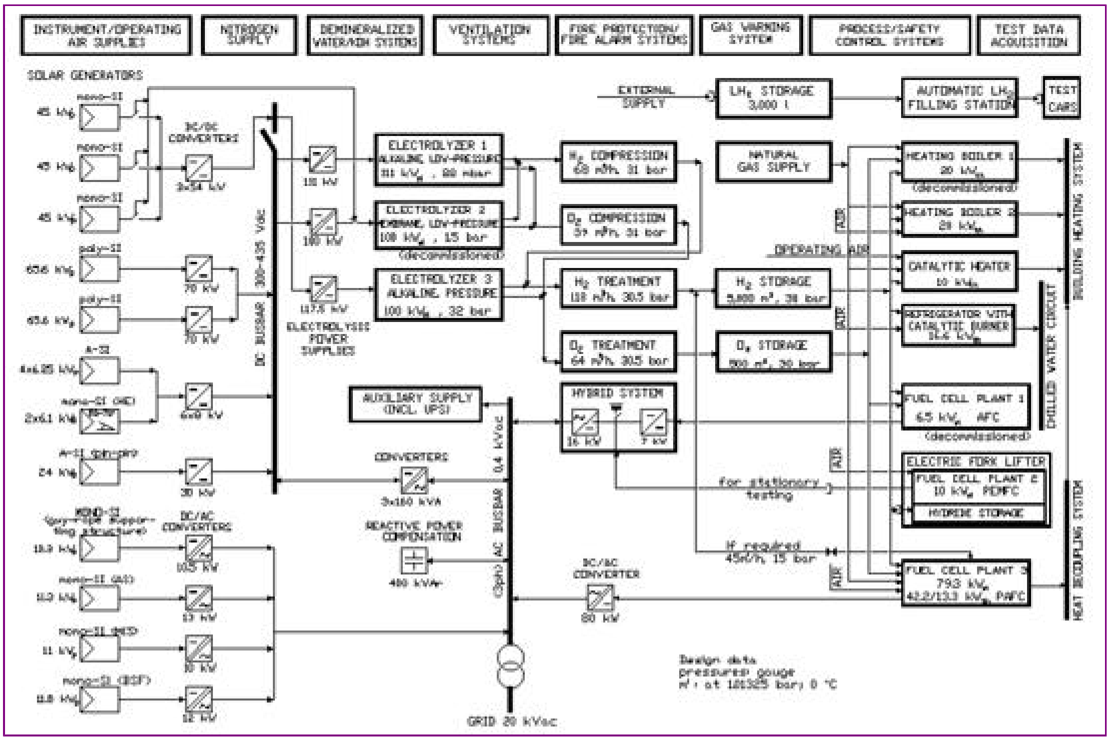

Figure 1: Block diagram of SWB solar hydrogen facility

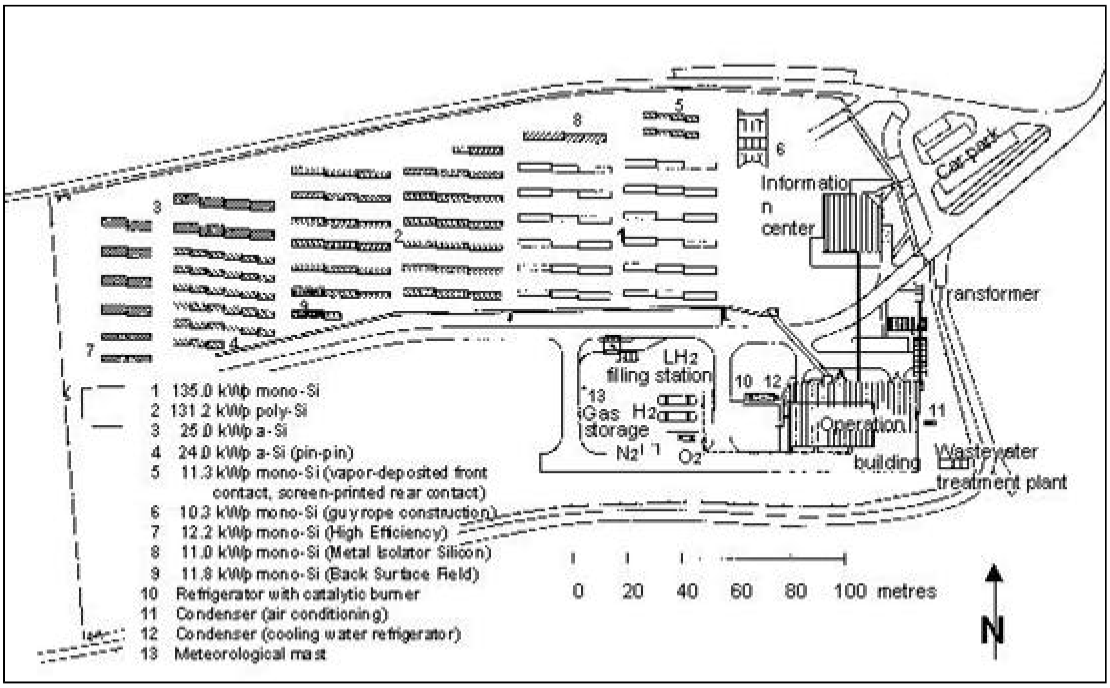

Figure 2: Site plan of solar hydrogen facility

We are concerned here mainly with hydrogen and above all the following aspects:

- Hydrogen's low density and viscosity increase the risk of leaks. The range of hydrogen's ignition limits in air is large, meaning that small concentrations of hydrogen in air or oxygen can lead to ignition and also that impurities of these gases in hydrogen must be avoided.
- Due to the low ignition energy, avoidance of ignition sources is a major safety consideration.
- The emission behaviour of a hydrogen flame needs taking into account in flame monitoring devices.

From the start it was clear that the components to be used in the hydrogen production and application systems did not conform to the requirements for siting in Explosion Protection Zone 1. This necessitated creation of environmental conditions to allow their classification under Zone 2 or lower, which stipulates, that an explosive atmosphere occurs only rarely and then only for very limited duration.

Primary safety measures

The purpose of primary safety measures is to eliminate sources of fault conditions, i.e. the formation of an ignitable mixture of hydrogen and air or oxygen.
To this end, the hydrogen is safely contained in the process components to the extent possible by appropriate design measures and use of approved materials of construction. Measures defined in a quality manual were implemented at all stages from the original planning to the final commissioning of the plant subsystems. These included review of production documents and data, inspections at contractors' works nondestructive testing of welds, pressure and leak tests, and visual inspection by a certified expert following installation and commissioning. Quality assurance input to be fulfilled by contractors was defined in technical specifications.

Diffuse leaks were prevented by design measures. Essentially these consist in preference of welded over screwed connections, use of bellows-type valves, magnetic-coupling compressors and controlled venting to the atmosphere.
Formation of ignitable mixtures due to ingress of air into hydrogen-containing components is prevented by continuously maintaining these under excess pressure. Highly critical items,

such as the first compressor stage suction lines operating at pressure close to atmospheric, are continuously monitored by redundant and diversified instrumentation and control devices.

Even in proper operating conditions, slight mutual contamination of the two gases hydrogen and oxygen or air occur in the electrolyzers and in the phosphoric acid fuel cell plant (PAFC). Actual mixing of the two gases can occur in malfunctions. Here again, redundant and diversified instrumentation and control is provided to ensure that any such fault is detected in due time and formation of an ignitable mixture is prevented.

Burner monitors also have the purpose of preventing hazardous accumulations of ignitable gas mixtures. For use on the gas-fired heating boilers and the reformer of the PAFC plant these devices had to be modified for operation with mixtures of hydrogen and natural gas. On catalytically heated equipment, flame monitoring was replaced by temperature monitoring.

Layout of the outdoor and indoors process systems at the plant site is designed to prevent major accumulations of gas in the event of hydrogen leakage occurring despite the protective measures described above.
The process components of the liquid hydrogen filling station are installed outdoors, because any leakage of liquid there would vaporize immediately and form corresponding gas volumes. Only minimum frost protection precautions are necessary and the installation is secured against unauthorized use by a wire fence that does not interfere with ventilation. The rain canopy is designed so that any hydrogen that might escape cannot collect under it (*Fig. 3*).

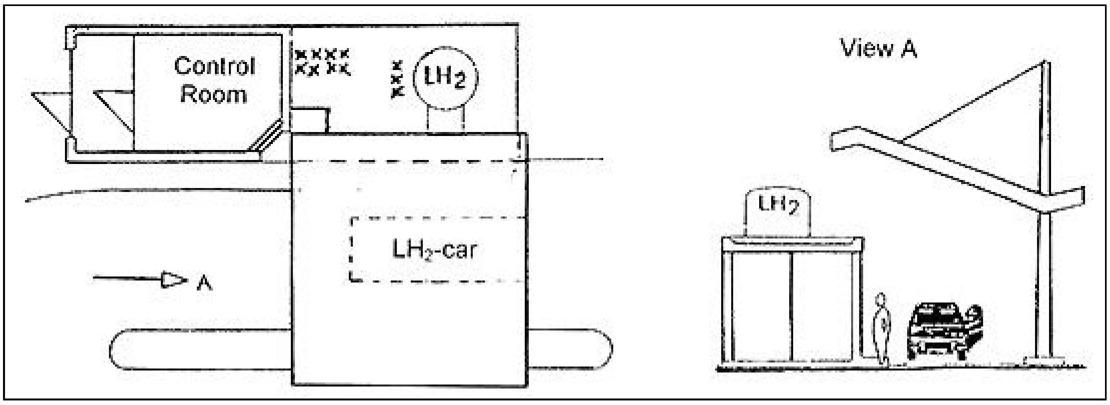

Figure 3: Layout of the liquid hydrogen filling station

Cable penetrations from the control room to the filling station are gastight, as is also the window provided for observation of filling operations. Together with the ventilation intake for maintaining excess pressure inside the control room, access to the room is located outside the explosion hazard area. With a view to possible escape of large volumes of gas in fault conditions, the pressurized storage vessel for hydrogen gas is located outdoors, at sufficient distance from the filling station and operating building (*Fig. 2*). Piping runs connecting the gas store to the operating building are installed in a trench covered by open-mesh grating.

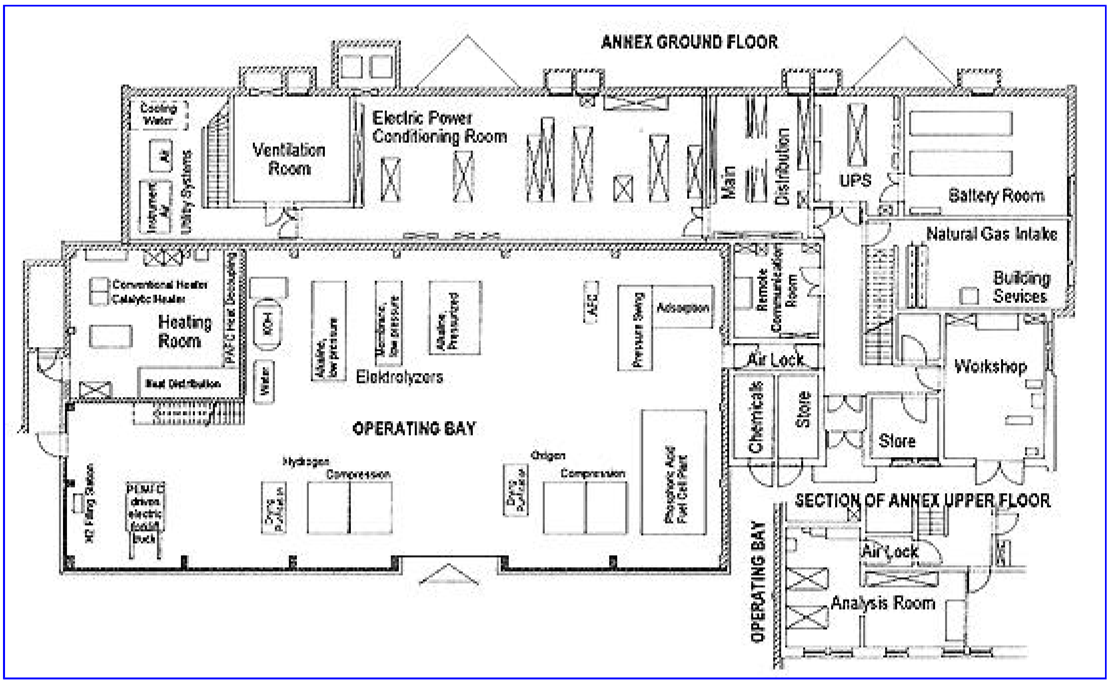

Figure 4: Layout plan of operating building

The operating building is constructed with two sections, namely the operating bay proper and an annex. Process systems containing hydrogen are housed in the operating bay, which is separated from the annex by a gastight and fire-retarding enclosure. The test-unit heating boilers and catalytic heater are installed in a separate room of the operating bay enclosed by gastight and fire-retarding walls with the sole entrance on the outside of the building. Access to the annex from the operating bay is through an airlock maintained at slight excess pressure to prevent passage of gas from the operating bay. Penetrations for cable and piping runs between the two sections of the building and between the heating room and operating bay are gastight so as to isolate the different explosion hazard zones.

Large accumulations of hydrogen in the operating bay and heating room are prevented above all by the hydrogen supply being reliably interrupted by redundant quick-closing valves if a set gas concentration is exceeded.

Adequate ventilation is an important primary safety measure with hydrogen systems in enclosed spaces.

The ventilation concept for the operating bay is based on studies of hypothetical faults, leaks from diffuse sources and piping breaks during hydrogen production or plant standstill while at operating pressure.

Natural ventilation of the operating bay is supported by continuous exhaust through openings at the summit of the 15-degree single-pitched roof. This is adequate to remove hydrogen escaping from diffuse leaks or the maximum enclosed volume of the plant in the shutdown state.

Mechanical ventilation of the filling station control room has already been mentioned. Those spaces in the operating building which are housing gas-containing components are mechanically ventilated. With regard to plant safety the ventilation systems have the task of preventing the formation of toxic or explosive atmospheres in any occurrence of gas leaks and avoiding entrainment of such atmospheres. This latter purpose is also served by the airlock between operating bay and annex and that leading to the analysis room in the annex (1st floor, so not shown in *Fig. 4*).

With the mechanical ventilation system of the operating bay, air can be blown in at the bottom of both long sides, caused to rotate in rolling waves and exhausted at the top so any escaping hydrogen is rapidly mixed with air and discharged to the atmosphere. During gas production, the fans are manually regulated to run at half speed.

Actuation of any detector of the gas alarm system (see below) causes the supply and exhaust fans to be switched automatically to maximum speed, ensuring air flow at rates conforming to explosion protection regulations for rapid dissipation of explosive atmospheres. Fan running is monitored by measuring differential pressure and any failure is signalled to the control room. Maintenance is performed on the ventilation systems only when gas production is shut down.

The heating room has a separate exhaust fan. Outdoor air is supplied close to floor level as a result of negative pressure while the exhaust air is removed under the ceiling and discharged

to the atmosphere. This fan is similarly switched to maximum capacity if any detector of the gas alarm system is actuated.
Separate supply and exhaust fans installed in the annex are primarily used for air conditioning and removal of heat gain from electrical components. Air flows in the analysis room, battery room and building services room (including the natural gas transfer station) are sized so as to avoid formation of an explosive atmosphere in the enclosed spaces.
The gas alarm system monitors gas concentrations via stationary detectors, actuates visual and audible alarms in the monitored rooms and control room when hazardous concentrations are detected, and, supported by the safety control system, initiates automatic countermeasures to prevent the formation of ignitable mixtures.
Areas monitored are the operating bay, heating room,analysis room, building services room, airlocks to operating bay and analysis room, control room and car entrance space of the liquid hydrogen filling station.
The detectors are located according to their function of air monitoring to detect presence of combustible gases (hydrogen and natural gas) and area monitoring to detect potential personal hazards due to oxygen excess or deficiency and toxic carbon monoxide. In addition to explosionproof detectors for air monitoring, hydrogen test sensors are installed, which do no initiate any corrective action but alarm concentrations by a tenth of the lower explosion limit and thus give operating personnel early warning of any faults.
Disposition of the detectors in the separate areas is displayed on a plant monitoring panel in the control room. Both limit values of all detectors are indicated separately so that personnel can immediately recognize the location and extent of any fault. Operating status of the ventilation in the monitored areas is also displayed (*Fig. 5*).

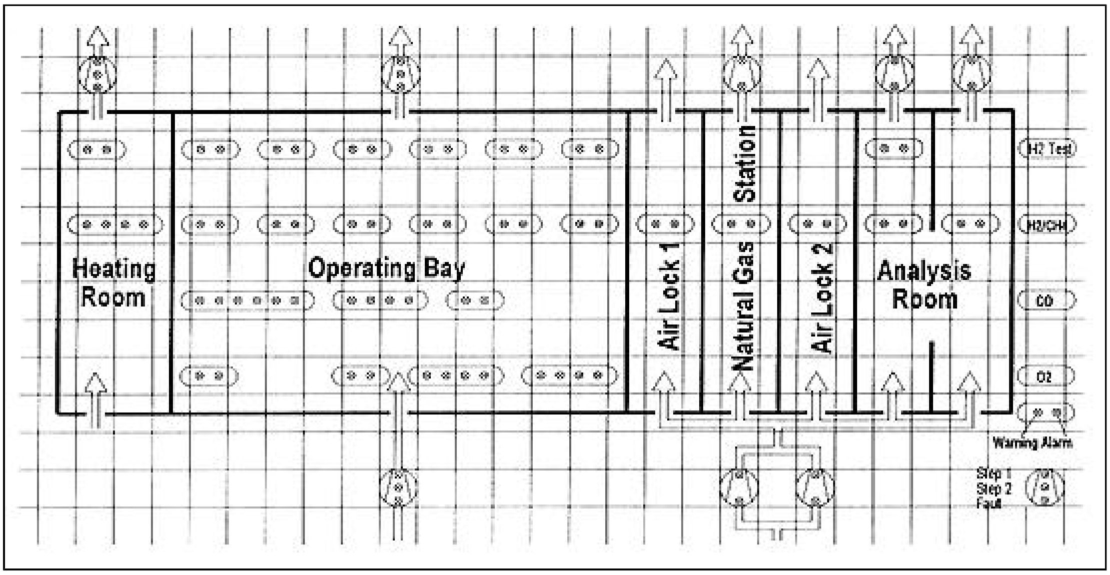

Figure 5: Part of plant safety monitoring system

In the occurrence of fault conditions and when the plant or parts of it are shut down or undergoing maintenance, formation of explosive mixtures can be prevented by inertization which consists in purging with nitrogen. A supply is kept in a liquid nitrogen tank with back-up cylinder batteries at the gas store and the purge gas is distributed in the operating bay via a ring main. The required nitrogen is fed to the systems through hose lines which are manually connected when necessary or under process control through fixed connections.Storage volume in the liquid nitrogen tank is monitored and low level is alarmed to the control room or, if the plant is unmanned, to the continuously staffed control room of Schwandorf Power Station at some 25 kilometres distance. Nitrogen serves for examples as a safe substitute for the process gas and as a heat transfer medium for unsupervised hot standby of the PAFC plant.
Helium is used for inertizing parts of the liquid hydrogen filling station, in which the low system temperature would cause nitrogen to freeze out and interfere with operation.

Secondary safety measures

Secondary safety measures consist in avoiding ignition sources of all kinds. It does not need

emphasising that smoking and use of open flames is prohibited in all hazard areas of the facility. Chief among other potential ignition sources are electrically or mechanically induced sparks.
Explosion protection classification accordingly requires that all electrical utilities within the operating bay are suitable for use in Zone 2, Explosion Group II C and Temperature Class T1. Specifically this means that in normal operationthey must not generate any sparks, arcs or temperatures above the ignition temperature of hydrogen.
In the gas store a protective zone is defined at a distance of 5 metres around the two hydrogen vessels and classified as Explosion Protection Zone 1, in which still higher demands must be met by the electrical utilities.
At the liquid hydrogen filling station, Zone 1 is in force within 3 metres around the valves of the site tank and Zone 2 within 5 metres of the vehicle filling connection. Electric potential equalization to avoid sparkover between plant equipment and earth or other plant equipment is accomplished by connecting all electrically conducting components to the grounding conductor which is in turn connected to the building reinforcing bars to ensure minimum ground resistance.
Low-sparking tools are used, when minor maintenance work is carried out during operation of the plant with while monitoring the surrounding area for combustible gases with portable alarm devices.

Tertiary safety measures

Should failure of both the primary and secondary safety measures occur, the extent of danger or damage arising as a result of faults must be kept as small as possible. Fire protection measures were coordinated with the local fire brigade and the Bavarian State Fire and Catastrophe Protection Agency. Firefighting water is supplied to the plant through the municipal drinking water main and the site firefighting grid. A manually operated sprinkler system is installed in the gas storage area for cooling the hydrogen and oxygen tanks in the event of fire.
A shielding wall of adequate height was constructed between the oxygen and hydrogen tanks so as to enable the safety clearance to be reduced from 10 to 5 metres.
The operating building is divided into two fire sections, namely the operating bay and the annex. The bay is divided into two and the annex into eleven subsections which are isolated by fire-resistant or fire-retarding measures in accordance with structural fire protection codes. The operating building is equipped with fire alarms working to various methods, installed in areas of high fire burden and in cable-conducting cellular floors. Actuation of the alarms is signalled at the safety control panel in the central control room. When the plant is unmanned, a signal is transmitted to the control room of Schwandorf Power Station, from where the necessary action is initiated under a defined emergency plan.
Pressure-relieving structures of the operating building are intended to reduce pressure build-up in the event of ignition of a combustible gas mixture. The separate panes of the row of windows on the north side of the operating bay are hinged at the top and fastened at the bottom by magnets of defined holding force so that they will open at slight rise in pressure. Another pressure-relieving structure is the large glazed area of and above the entrance gate. So as to further define the direction of pressure relief, the cast in situ concrete walls adjoining the annex are constructed stronger than the external curtain walls of prefabricated concrete slabs, which in turn are stronger than the aerated concrete roof covered with roofing tiles. Escape routes in the operating building were defined together with the agencies responsible. Emergency lighting ensures that the exit signs are visible even in a main power failure.

General safety measures

Mention has already been made of the safety control system. Safety-relevant functions are implemented through this hard-wired fail-safe relay control system (*Fig. 6*).
The safety control system processes safety-related signals originating from the monitoring systems, plant subsystems and auxiliary systems. It transmits alarms to the operating personnel or, when the plant is unmanned, to Schwandorf Power Station. Automatic countermeasures initiated by the system include maximization of mechanical ventilation and shutdown of plant subsystems and power supplies. At all times the safety control system has priority over the process control system.

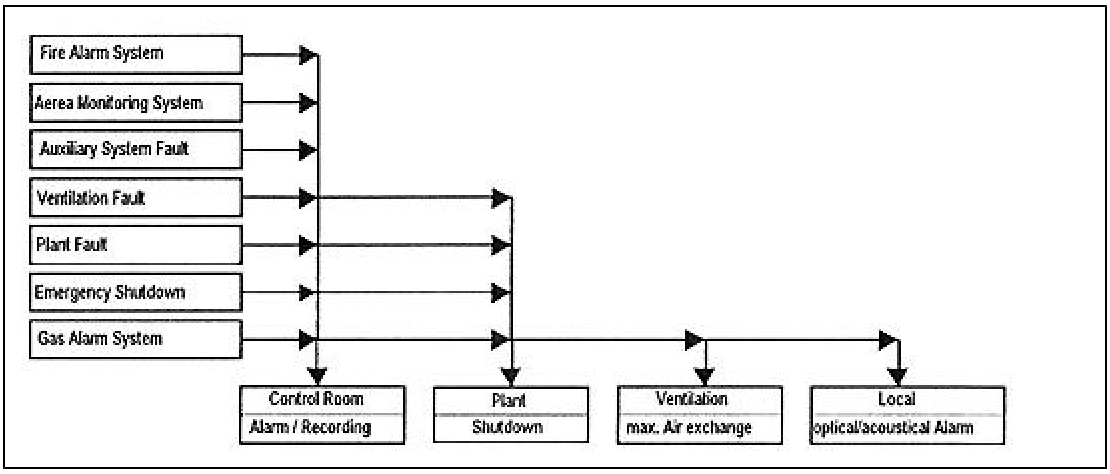

Figure 6: Matrix of safety control system

The control system and the safety-related electrical equipment are connected to the uninterruptible power supply. When the plant is unmanned, line power failure is alarmed to the control room of Schwandorf Power Station. Battery capacity is designed to give sufficient time for installing an emergency power generator. Valves that have safety functions operate to the well known fail-safe principle.
The operating manuals list safety measures that are performed by operating personnel, not automatically, and instructions for maintenance and service procedures intended to ensure safe operation of the plant.
Operating instructions have also been issued for the action to be taken in accidents and other hazard conditions.
Instruction given during the commissioning of plant systems and regular briefings on safe working with the plant are part of operating personnel training.
Maintenance and servicing work which may entail hazards to personnel or impairment of plant safety may only be carried out when a work permit with disconnection voucher is issued. The disconnection voucher enumerates the safety measures required before commencing the work and also those required for safe restarting.
Regular inspections for the protection of employees and third parties are prescribed both by law and by the workmen's compensation society. These include above all inspections under the German Pressure Vessel Code, inspection of electrical equipment in explosion-hazard areas under German Explosion Protection Code, inspection of gas-containing systems for leaks, and inspection of gas alarm devices. In accordance with the rules and requirements, these inspections are undertaken by independent inspectors, external service contractors, the service department of Schwandorf Power Station, or operating personnel of the solar hydrogen plant.
The prescribed inspections are supplemented by routine checks undertaken by the operating personnel, for instance visual and audible checking for leaks.

Results

The safety concept devised for the solar hydrogen plant at Neunburg vorm Wald and the measures implemented under this concept were not required to cover any safety risks of a fundamentally new nature, but new applications.
Hydrogen, in both gaseous liquid form, has been in regular use for decades and the existing regulations are adequate for safe working with this substance, at least in industrial applications.
Experience gained with operation of the plant to date has not furnished cause to amend the concept toward providing a still higher level of safety. It has been possible to satisfy all requirements of preventing injury to persons at the plant, damage to property and detriment to the environment.