SWR-1000 CONCEPT ON CONTROL OF SEVERE ACCIDENTS

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Abstract

It is essential for the SWR-1000 probabilistic safety concept to consider the results from experiments and reliability system failure within the probabilistic safety analyses for passive systems. Active and passive safety features together reduce the probability of the occurrence of beyond design basis accidents. Mitigative measures are incorporated into the SWR-100 design to cope with core melt accidents in order to limit their consequences in accordance with the German law. As a reference case we analyzed the most probable core melt accident sequence with a very conservative assumption. An initial event, stuck open of safety and relief valves without the probability of active and passive feeding systems of the pressure vessel, was considered. Other sequences of the loss of coolant accidents lead to lower probability.

1. Introduction

According to the German atomic law NPP's only will get an operating license if precaution measures have been incorporated in the design which practically prevent the occurrence of severe events. If hypothetically a core melt accident is being considered, the consequences to the environment do not lead to evacuation or relocation of the population living in the plant vicinity. The structures of the plant have to withstand the impact of the core melt accident without to permit release of radioactivity to the environment.

2. Frequency of core melt accidents

The safety concept of the SWR-1 000 fully complies with the specified requirements. Active and passive safety features together reduce the probability of the occurrence of beyond design basis accidents. On the other hand mitigate measures control the core melt to the highest extent possible to prevent consequences according to German laws. Preliminary probability concept analyses due to internal events during operation leads to core damage frequencies, which are much smaller as from external events. The plant can not be designed against extreme earthquake forces or other cosmic events leading to disintegration of the reactor building. As a very conservative assumption the most probable core melt accident sequence is being selected as a reference case in fulfilling the requirements of the 7th atomic law (deterministic assumption). For the SWR-1000 as initial event stuck open of safety and relief valves are determined without the possibility of active and passive feeding of the reactor pressure vessel. Other sequences of loss of coolant accidents leads to lower probability figures.

Within the probability analyses for passive systems the results from experiments and feasible system failures have to be considered.

- Concept to control the core melt

To control the core melt in the SWR-1000 design the following targets have to be considered:

- Retention of the core melt in the RPV by cooling the RPV from outside.
- Inertization of the containment with N_2 to prevent H_2-explosion or deflagration.
- Consideration of the H_2-content generated by 100% Zirconium-water reaction for the containment design.
- Passive release of heat from the containment
- Pressure reduction in the containment within a certain grace period of several days via the off-gas-system

In the following chapters the various countermeasures to control the various events are described.

- Prevention of core melt under high pressure in the reactor pressure vessel

The high pressure core melt can be prevented in the SWR-1000 design by the multiredundant and diverse features for pressure reduction. Compared with the RSK-recommendations for the EPR pressure release features could be defined as reliable if they work such as a safety valve for pressure limitation.

In all BWR-plants as a matter of principle reaching of a very low water level in the RPV or during pressure increase in the containment an automatic pressure relief function is being initiated by the reactor protection system enabling low pressure feeding of the RPV. The pressure limitation and reduction features of the SWR 1000 compared to current systems have been extended (see fig 1).

8 safety and relief valves with redundant and diverse pre-control valves are incorporated in the design.

For the function pressure limitation for each of the valves passives spring loaded pre-control valves and for each valve a magnetic pre-control valve are actuated by the I and C-system.

For the function pressure relief for each valve passive pulse generator operated membrane control valves are used and magnetic pre-control valves are actuated by the I and C-system.

During initiation of the pressure relief function the main valves remain open (mechanically blocked) as a back-up solution rupture discs are in stalled which start their function if the design pressure is reached. In case of a failure in the I and C-control system or loss of electricity from batteries the complete functions for pressure reduction are granted by that passive safety features. During loss of the pressure relief functions but well working operating pressure limitation the 4 emergency condensers take over the pressure reduction function. The capacity of the system enables reduction of the reactor pressure down to the operating level of the active decay heat removal systems (<10 bar). Core melt under high pressure is excluded by these means.

- Prevention of steam explosion in the RPV

Is the active and passive feeding being lost under low pressure the core starts melting. With progress of the core melt process the material flows into the lower plenum of the RPV, filled with water and the possibility of a steam explosion has to be considered.

A heavy steam explosion leading to a disintegration of the RPV needs an intensive mixture of core melt material with water. Following the literature the general probability of a heavy steam explosion is considered rather low and depends from the mode of the core melt process: Various possibilities how the core melt could get into contact with the water for initiating a steam explosion have been analyzed.

The core melt will solidify on the surfaces of the control rod guide tubes and the control rod drives or other structural materials. Countermeasures to prevent steam explosion are not necessary.

- Retention of a core melt in the RPV; outside cooling.

To prevent a disintegration of the RPV as a consequence of the accumulation of the molten material in the lower plenum of the RPV, an outside RPV-cooling system grants the integrity of the RPV walls and thus the release of the melt into the containment.

The cavity housing the RPV (pressure chamber) is flooded with water. Via respective piping systems the water is transferred from the flooding pool into the pressure chamber. The water level in the pressure chamber is being controlled on the same level as in the flooding pool which is adjusted to the level on which the emergency condenser is working. The details of that design are still under investigation. A passive initiation via pulse generators or melting barriers and manual interference may be feasible. In any case a malfunction during operation is prevented.

Heat transfer from the core melt collected in the lower plenum of the RPV to an outside located cooling system without exceeding the critical heat surface loads, i.e. without film boiling is possible.

The water inlet into the cooling features between reactor pressure vessel wall and insulation needs a space of 1 mm. Only for the central control rod drive tube nozzle a 10 mm space is necessary. 8 penetrations of 300 mm Ø in the RPV-support grants for an undisturbed release of the water-steam mixture. In the upper area the steam leaves the pressure chamber via the pipe penetrations, which carefully have to be designed for this purpose (see fig 2).

Investigations with the FE-code Adina-F concerning behavior of the core melt in the lower plenum leads to the expectation of rather small impact to the RPV-walls. Figure 3 shows the core melt in the lower *plenum of* the RPV with oxidized surface layer. In the area between metallic and oxidized melt the highest heat transfer transaction into the lower part of the RPV is predicted, which leads to rather small melting of the lower plenum RPV material. The pressure load capability of the RPV is not being reduced(see Fig. 4). Melting of the control rod nozzle or pump nozzle due to the outside cooling is not expected. The cooling capability of the control rod flushing water and the seal water for the main pump nozzles is not considered.

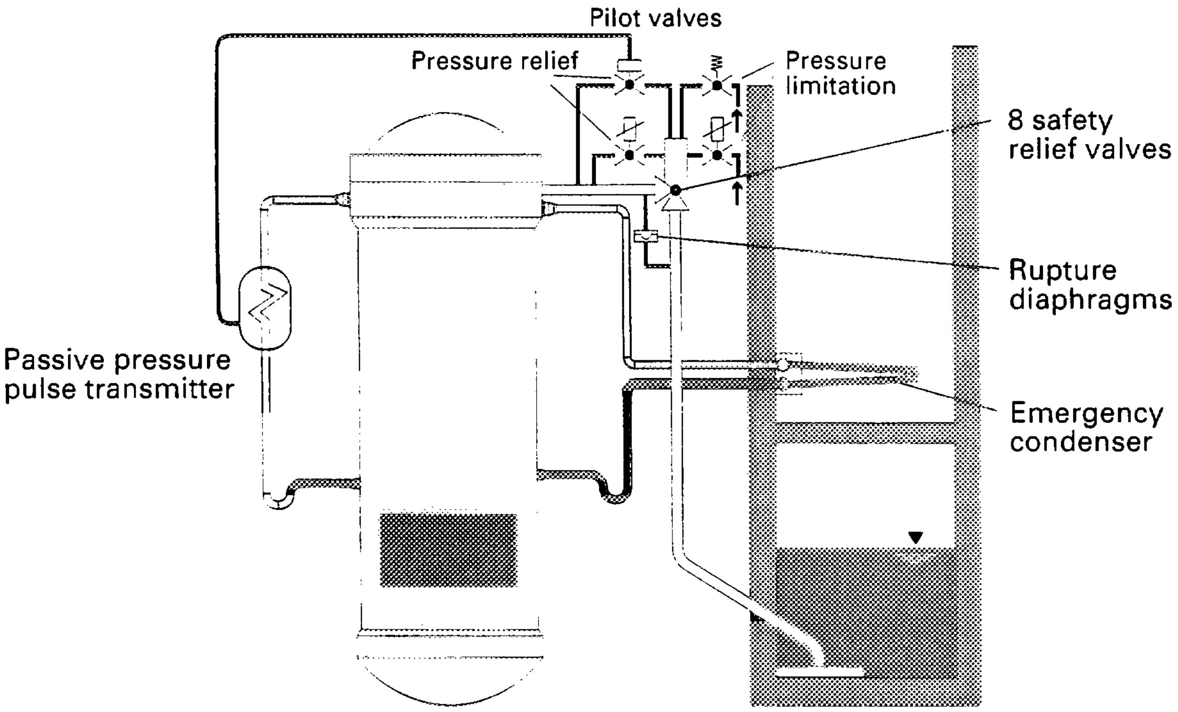

FIG. 1. Pressure relief system for reactor pressure vessel.

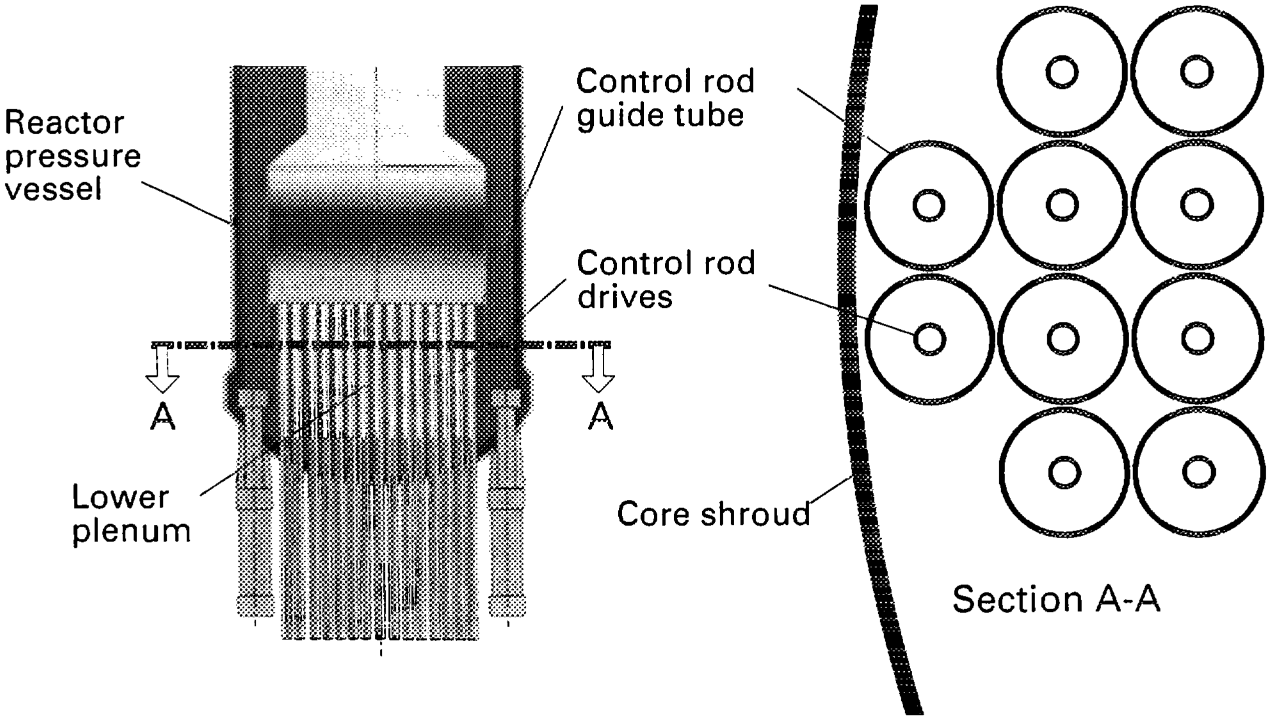

FIG. 2. Core components in lower RPV plenum.

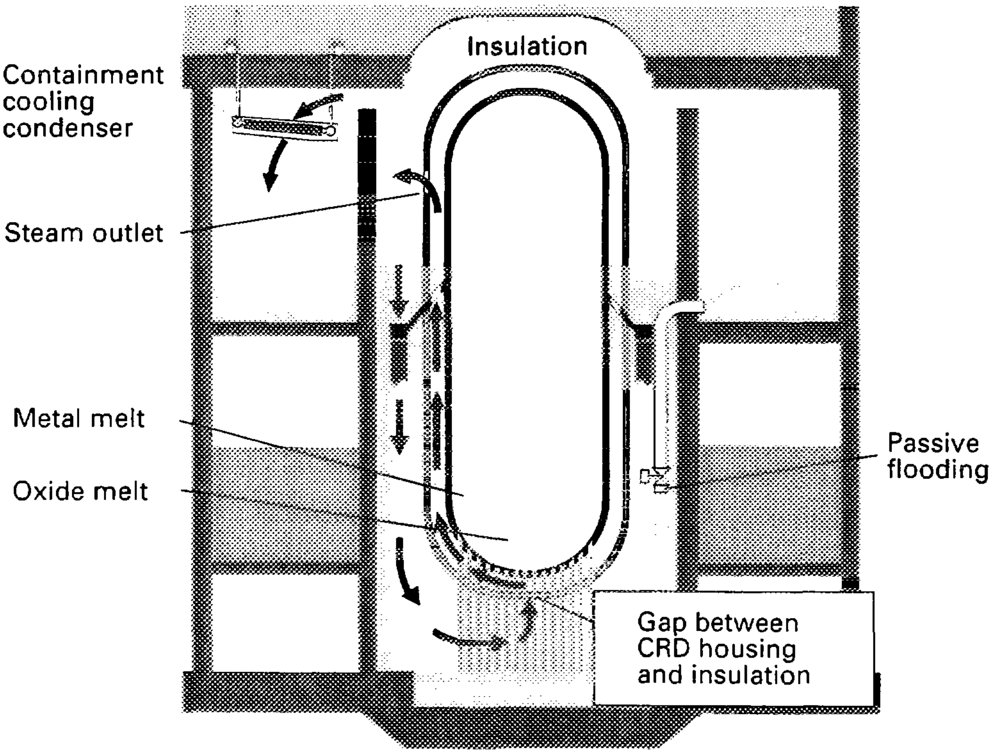

FIG. 3. External cooling of RPV during core meltdown.

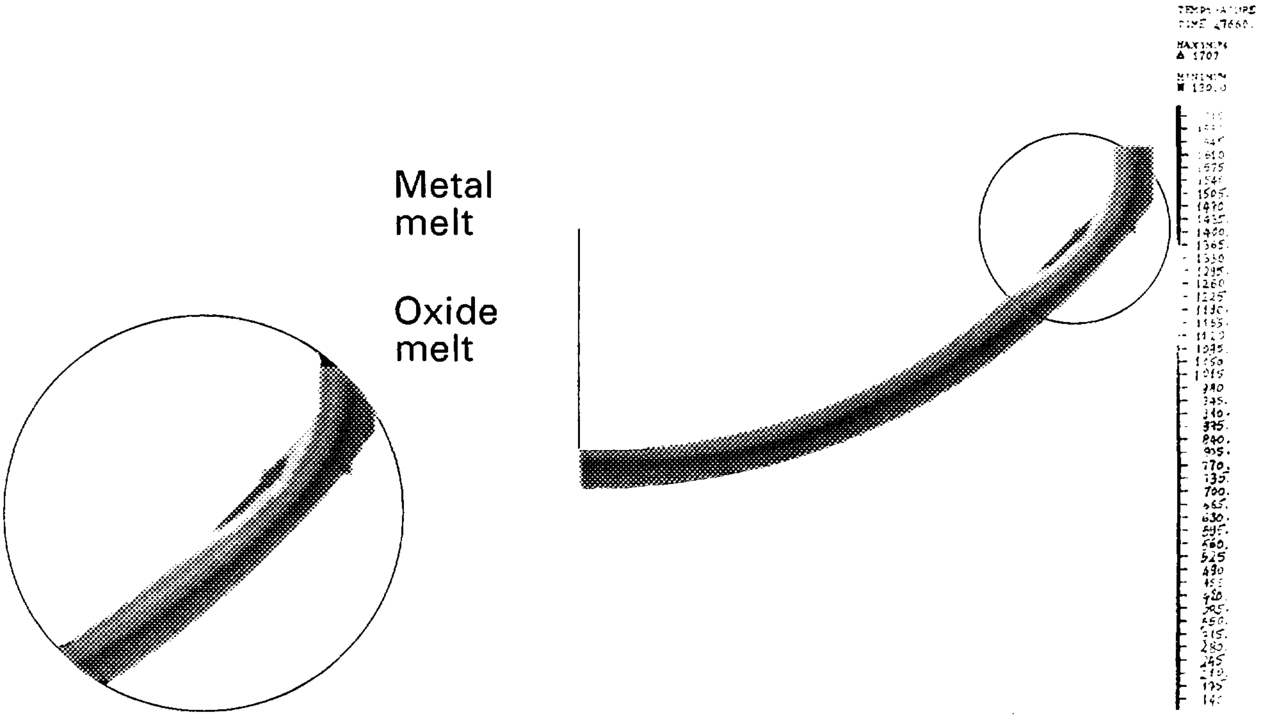

FIG. 4. Temperature of RPV bottom head during core meltdown.

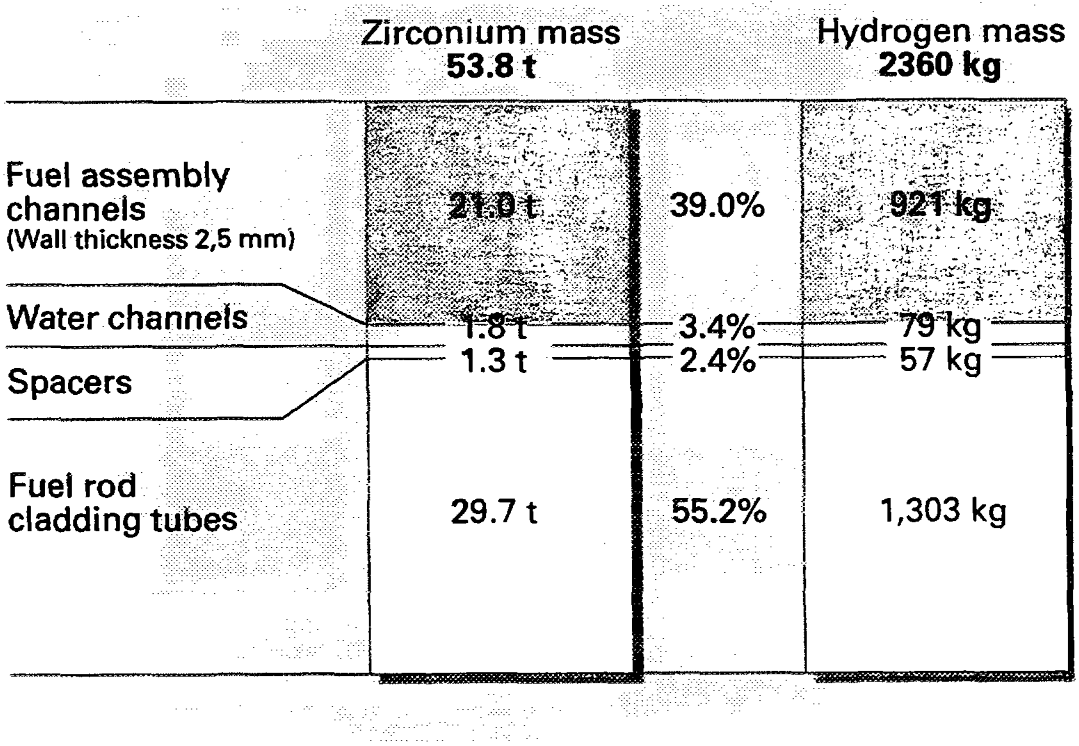

FIG. 5. Hydrogen produced by zirconium-water reactor in reactor core.

A release of the core melt from the RPV into the containment can reliably be prevented. Thus steam explosion or an interaction between concrete and the melt material is excluded.

- Recriticality

Recriticality after severe accidents only has to be considered if the geometry and composition of fission material, moderator and absorber are as favorable as before the disintegration of the core. This configuration is only feasible within a homogeneous fine fragmentation of the core material without significant parts of absorber material, but with an optimal moderator distribution inside the fragmented material.

For the BWR general a recriticality is highly improbable because of the unfavorable neutron economic structure of the core melt compared with the original core structure. The core may start melting from the lower core grid plate and the melt will drop or fragmented into the bottom part of the vessel. The early melting absorber material B_4 C-Fo from the control rods is located in the melting zone thus poisoning the fragmented material and the melt droplets. This kind of poisoned no homogeneous material remains uncritical. For the SWR-1000 recriticality of core melt material is excluded.

- H_2-Production, Prevention of H_2-ignition

In the core melt the Zirconium reacts with water and steam whereby H_2 is being generated. For the containment design pressure 100 % water/Zirconium reaction is being considered. A small quantity of H_2 is generated in the radiolyse-gas-production process. The

100 % H_2 /Zry reaction is a very conservative assumption, also other metal-water reactions are already covered by this assumption. With the core mass of 53,8 t (fuel cladding tubes, water channels; spacers and fuel channels) 2360 kg H_2 will be generated (see fig. 5). Core melt calculations usually consider a < 40 % Zry/Water-reaction.

To prevent a reaction of the H_2 with O_2 the containment will be inerted. Detonation or deflagration are prevented. To prevent an impermissible increase of O_2-concentration by the radiolytic process a number of recombiners will be installed (the number will be decided later).

- Heat transfer from the containment

For heat transfer out of the containment two active residual heat removal systems and four emergency condensers will be available. A complete passive heat transfer from the containment after 100 % failure of the active residual heat removal systems is possible via the water volume stored in the flooding pool. The steam generated from the outside cooling of the RPV will be condensed in the building condenser, the condensate is collected in the flooding pool. The condensation heat is transferred to the pool water, which is cooled via the containment condenser by natural circulation.

The H_2-quantity in the reference case could be stored in the condensation chamber thus the steam condensation in the buildings condenser is not being influenced. Assuming larger quantities of H_2 parts of the gas will be released into the pressure chamber. The containment condensers are designed for a inert gas mixture and are located at a level allowing collection of H_2. Deterioration of the heat transfer conditions leads to a pressure increase in the pressure chamber and flushing of H_2 in the condensation chamber. By these measures the passive heat transfer also in case of H_2 release is granted.

Interference of operating staff will only be necessary after evaporation of the 2200 m^3 water stored in the flooding pool. These conditions may be reached after 3 days after the accident. Reflooding of the pool easily can be performed by the fire brigade.

- Design pressure of the containment

The main parameters for which the containment has to be designed are the released heat from the RPV and the generation of steam by means of the decay heat which leads to a temperature and pressure increase in the condensation chamber and the flooding pool. Additional pressure increase following a core melt accident is the Zry/H_2O-Reaction, an exothermic reaction. Further increase of temperature and pressure has not to be assumed due to the inertization.

In the design of the containment the various inputs are considered. Realistic conditions of the gas distribution in the containment, the heat capability of the building structures and the 100 % Zry/H_2 0 reaction leads to a design pressure of 7,5 bar. The pressure can be attained by using the passive safety systems and will decrease during the long term mode operation.

- Pressure reduction in the containment

With respect of the H_2 production during a core melt accident the pressure would not be reduced only by cooling. Specific features are necessary for pressure reduction in the

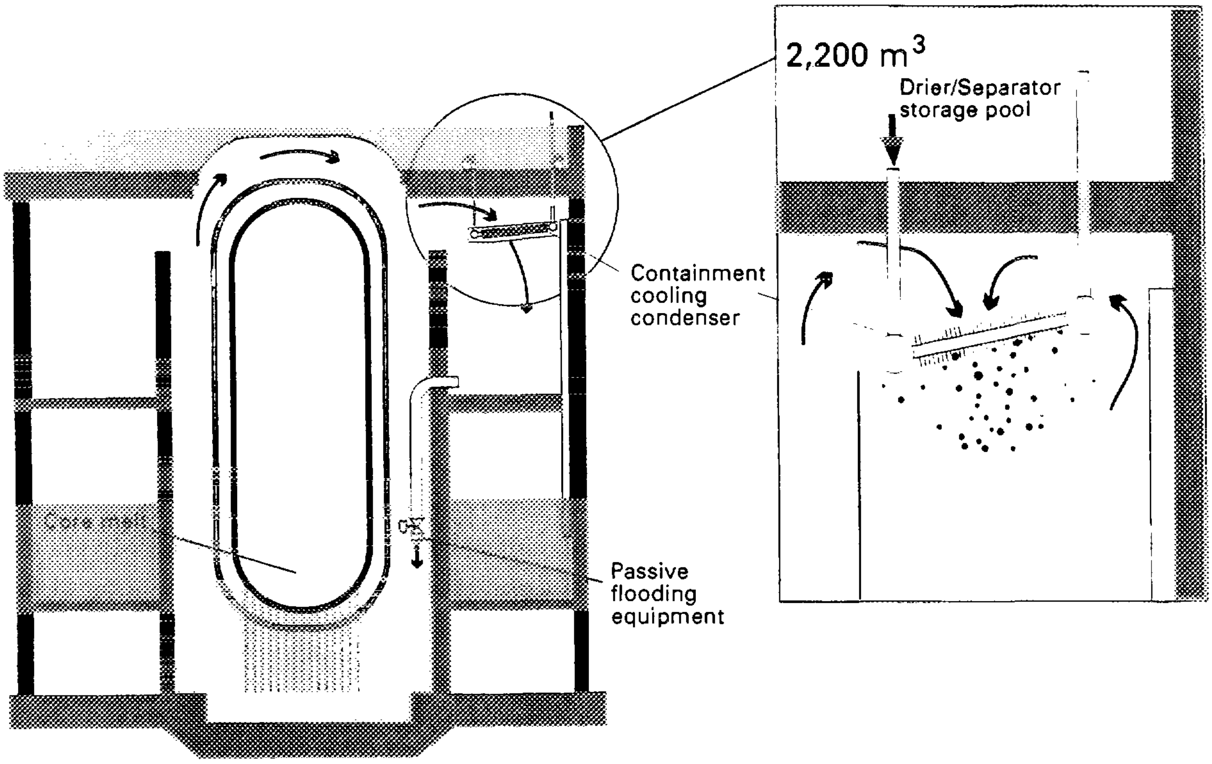

FIG. 6. Passive heat removal from containment during core meltdown.

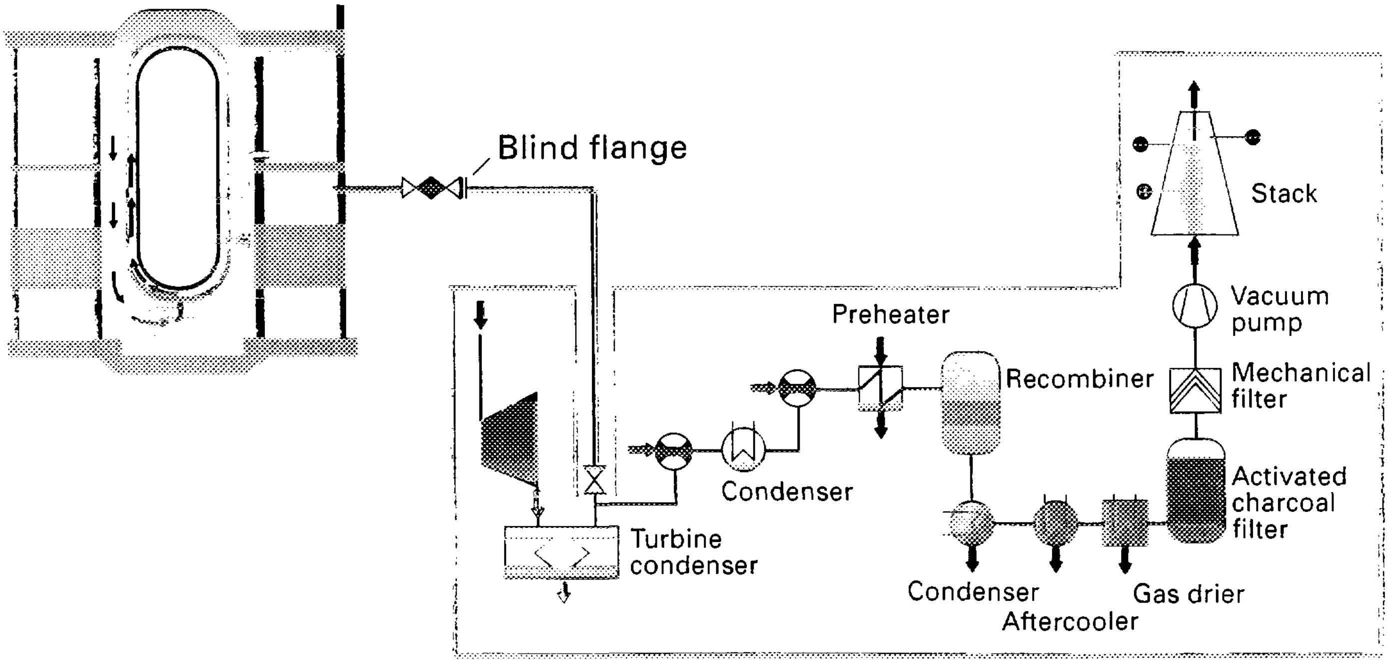

FIG. 7. Reducing the pressure in the containment following a severe accident.

containment (see fig. 6). For this purpose the off-gas system with recombiners and activated charcoal filters are being used. A small pipe connection between containment and off-gas-system is foreseen. This pipe is connected with the gas plenum of the condensation chamber and isolated by two valves and a blind flange. The pipe can be opened if needed. Aerosols are removed from the gas mixture by means of the washing process in the condensation chamber (99 %). The H_2 together with 0_2 will be recombined in the recombiners to H_2 0. The dry inert gases (noble gas) will be send to the activated charcoal filter for radioactive decays. The decay time for Krypton is approx. 3,6 days and for Xenon 60 days. After the pressure reduction phase which lasts approx. 40 h the offgas-system will be isolated for decay of the noble gases (see fig. 7).

3. Summary

The safety concept for the SWR-1 000 consisting of diversified passive and active safety features limits the probability of occurrence of sever condition to rather low figures due to internal events. The concept of control of postulated core melt is based on the retention of the melt in the RPV by external vessel cooling. For this purpose a passive flooding system is foreseen.

To prevent a core melt under high pressure in the RPV redundant and diverse safety features are installed for pressure control.

A steam explosion can be excluded during release of the melt and collection in the water filled lower plenum of the RPV due to the existing structures.

H_2-fire in the form of deflagration or explosion in the containment is prevented by inertization. A steam explosion in the containment or an interaction between concrete and core melt with all consequences is excluded.

The heat can be transferred out of the containment via the passive building condenser.

The pressure can be reduced via the offgas-system and the activated charcoal decay beds without to permit release of radioactivity into the environment.

This concept fully complies with new German law from 1994.