J 1/4

Structural Engineering Problems Due to Hypothetical Core-Melt-Accidents

G. Schnellenbach, P. Bindseil
Zerna, Schnellenbach und Partner GmbH, Viktoriastr. 47, D-4630 Bochum 1, Germany

Abstract

The contribution of concrete structures to the decrease of radioactive release in case of hypothetical core-melt accidents has conservatively been neglected up to now. The aim of this paper is, to give a survey on some interesting and essential structural problems which have to be investigated to get an answer to this question. Thereby it should be considered that even a reduced integrity of the structures still may help to delay and thereby decrease the finally released radioactivity.

First numerical approaches have been done. Their results are encouraging. More detailed investigations have just been started for phase B of the German Risk Study on PWR's.

1. Introduction

In spite of their extreme low probability of occurance, core- melt- accidents have been object of investigations for a long time. Quantitative estimations of possible accident results were given in the reports WASH-1400 and in the German Risk Study on PWR's some years later. These results were to some extend based on rather conservative assumptions, and there is good evidence that these former reports give a fairly high over- estimation of radioactive release.

To get more knowledge of the real conditions advanced studies are carried out in Germany. To perform them, not only refined data concerning thermo-dynamics, nuclear chemistry and distribution of aerosols are necessary, but also a more detailed knowledge on the behaviour of the involved building structures, especially the reactor building. (These studies should give information about the behaviour of standard PWR-power-plants without any modification).

The aim of this paper is, to give a survey on structural engineering problems arising from hypothetical core-melt-accidents.

The knowledge of structural behaviour is important for two reasons:

- The structures, even in case of reduced integrity supply an additional barrier against the release of radiocativity.
- The behaviour of some structures interacts with the course of accident.

The investigations are related to the situation of a typical German PWR-power-plant, see fig. 1, and the paper is restricted to the concrete structures inside and outside the steel containment.

2. Some Remarks on Core-Melt-Accidents.

A core-melt-accident may be initiated by different events. The following remarks are mainly related to an accident sequence which is started by a rupture of a main coolant pipe and additional breakdown of emergency coolant systems.

The core-melt-sequence can be divided into four phases. The first and second phase take place inside the reactor pressure vessel. During the third phase the meanwhile molten core and structure materials penetrate through the bottom of the vessel and get in contact with different concrete structures. During the fourth phase the molten materials will cause a cavern in the concrete of the bottom slab of the reactor building by melting the concrete.

Theoretical investigations based on tests indicate that the melting of the concrete will be a rather slow process and - far from the China syndrom - probably will come to a standstill even within the slab thickness, see ref. /1/. It should be pointed out, that the development of structural behaviour during the accident is of interest, even in those hypothetical cases where a final collapse may be unavoidable. The longer a structure can withstand the affections the more effective is its contribution to a reduction of radioactive release.

3. Affections on Concrete Structures

The core-melt-sequence outlined above causes different affections on the concrete structures of the reactor building. These are mainly (see fig. 2):

- direct weakening of structures by melting. Thereby other parts of the structures can be weakened indirectly,
- loads on structures like inner pressure and high temperatures.

The melting process is of influence on some structures inside the steel containment and especially on the central part of the bottom slab.

During all phases of the core-melt-sequence an over-pressure is built up in the steel containment mainly due to hot steam, see references /1/ and /2/.

In case of a tight containment structure this pressure will lead to the rupture of the steel containment at an absolute pressure of nearly 9 bars after approximately five days (t_1), see fig. 3. This event is called (see e.g. /2/) the release-category FK 6. It causes the extreme load conditions for the concrete shell outside the steel containment.

In case of a defined leak in the steel containment (this is referred to as the release-category FK 2) the pressure built-up in the containment will be lower and consequently the loads on the outer concrete structure likewise.

It is not yet finally cleared wether the assumption of steam explosions due to contact between molten material and water, especially within the reactor pressure vessel, and of hydrogen deflagrations or detonations in the steel containment is realistic. Recent investigations by Mayinger /3/ and Hosemann /1/ indicate that both events seem to be highly improbable when the real physical conditions are taken into account. Therefore the structural problems (which would be rather challenging) arising from these phenomena will not be dealt with in this paper.

Especially the following structural parts of the reactor building will be of influence on the refined estimation of radioactive release by their behaviour during the core-melt-sequence. These are:

- The bottom slab
- The enclosing concrete shell outside the steel containment.

Structures inside the steel containment can only be directly injured by melting in a limited central region under the reactor pressure vessel. At the present status of investigations possible influences on the overall stability of the inner concrete structures seem to be of no severe consequences.

4. Weakening and Residual Stability of the Bottom Slab due to Melting of the Concrete in the Central Part of the Slab

The behaviour of concrete in contact with the molten core- materials is still under investigation by tests and theory, see e.g. reference /1/, but the first results show that by melting the concrete a cavern will propagate into the bottom slab, in horizontal (i. e. radial) and vertical direction as well.

This central weakening of the bottom slab has several aspects. A local one is the demand, that during phases of low inner over-pressure the weakened central part of the slab should not fail due to ground-water pressure. In a first approach the minimal slab thickness under the cavern (as a function of different supposed radii of cavern) which is necessary to avoid failure of the slab with flowing in of ground-water has been investigated. This has conservatively been done for a rather deep embedment of the reactor bulding. The results are encouraging, showing, that such a type of failure will (if ever) occur only a very long time after the begin of core- melt-accident. However, more detailed calculations will be done as soon as refined knowledge is available about the extension of the melted cavern.

The weakening of the bottom slab has global effects, too: calculations have been performed to investigate the overall stability of the bottom slab as structural part of the whole reactor building. The calculations were based on different conservative assumptions concerning the extension of the melted region. The calculations showed that there is a limit for the cavern diameter up to which - in spite of extended deformations and cracks of the slab - the global stability of the slab and of the whole reactor building is not affected. It seems that this limit will not be reached by the melting process. More detailed calculations especially on the transient temperature distribution in the vicinity of the melted region and on the temperature induced stresses and cracks in the slab itself are recommended.

5. Permeability of Enclosing Concrete Structures to Accident Atmosphere

Even after failure or leakage of the steel containment (as has been discussed in chap. 1) the enclosing concrete structures supply an additional barrier against direct radioactive release to the atmosphere. This has been neglected up to now. The degree of permeabilty should be quantified as a function of cracking of the concrete structures, the main contribution coming from the structural parts above ground level. Thus in a first approach the investigation can be restricted to the outer wall of the reactor building. It has to be pointed out that in modern German Power Plants these structures are designed for heavy aircraft impact and therefore contain a good deal of mild reinforcement, but they are not designed against inner pressure in case of LOCA, this being the task of the inner steel containment.

This reinforcement provides a certain bearing capacity against inner pressure but the structure is of course not able to withstand the hypothetical over-pressure (approximately 7 bars), which would built-up in case of release- category FK-6 under the theoretical assumption of full tightness. Therefore extended cracking will occur which will start, according to reference /4/, at an inner (absolute) pressure of approximately 2 bars in the circumferential direction of the cylindrical shell and at approximately 3 bars in the other regions of the shell. With increasing pressure the cracks will penetrate through the whole cross-section, inspite of temperature-induced compression on the inner surface.

The permeability of the cracked concrete walls depends linearly on the inner pressure and on the third power of the crack-width and therefore strongly on the crack distribution. On the other hand permeability means leakage and this implies a slower increase of pressure by which again the process of cracking and the increase of permeability slows down.

The interaction of increasing pressure, extending cracking and permeability has not yet studied in detail. Only first approaches have been done with rather conservative assumptions, especially towards concrete cracking.

The leakage rate, which increases approximately with the third power for increasing pressure, prevents a pressure built-up which may endanger the overall-stability of the shell structures. Again the factor of time should be regarded, too: The pressure built-up within the concrete shell (and so the development of successive cracking) needs time and therefore delays the direct release of radioactivity to the atmosphere, an effect that has been neglected totally up to now. This delay may have two positive effects:

- There is more time to start counter measures especially outside the plant
- Because of adwanced radioactive decay and of condensation and deposit of radioactive materials in the interior of the structures, the finally released radioactivity will be lower than calculated without taking into account the reactor building.

6. Some Final Remarks

The contribution of concrete structures to the decrease of radioactive release in case of hypothetical core-melt accidents has conservatively been neglected up to now. The aim of this paper is, to give a survey on some interesting and essential structural problems which have to be investigated to get an answer to this question. It has been pointed out, that even when it is not possible to guarantee the stability of the structures, a reduced integrity still may help to delay and thereby decrease the finally released radioactivity. The dominant influence of time is pointed out.

First numerical approaches have been done. Their results are encouraging. More detailed investigations have just been started for phase B of the German Risk Study on PWR's.

References:

/1/ J.P. Hosemann "Wechselwirkungen mit der Containmentstruktur und Spaltproduktfreisetzung", Vortrag auf der Jahrestagung Kerntechnik 1982, Fachsitzung "Möglichkeiten und Auswirkungen schwerer Reaktorunfälle"

/2/ K. Hassmann: "Thermodynamik im Sicherheitsbehälter bei verschiedenen Kernschmelzabläufen", Vortrag auf der Fachtragung der KTG im Kernforschungszentrum Karlsruhe, 1982

/3/ F. Mayinger, "Wie sind Dampfexplosionen im Lichte neuerer Erkenntnisse zu beurteilen?", Vortrag auf dem 5. GRS-Fachgespräch 1981, 23.10.81 in München.

/6/ Zerna, Schnellenbach und Partner: Abschlußbericht der Studie BMI SR 198 B, "Alternative bauliche Ertüchtigungsmaßnahmen oberirdischer Kernkraftwerke im Vergleich zur unterirdischen Bauweise für extreme Belastungen", 1981

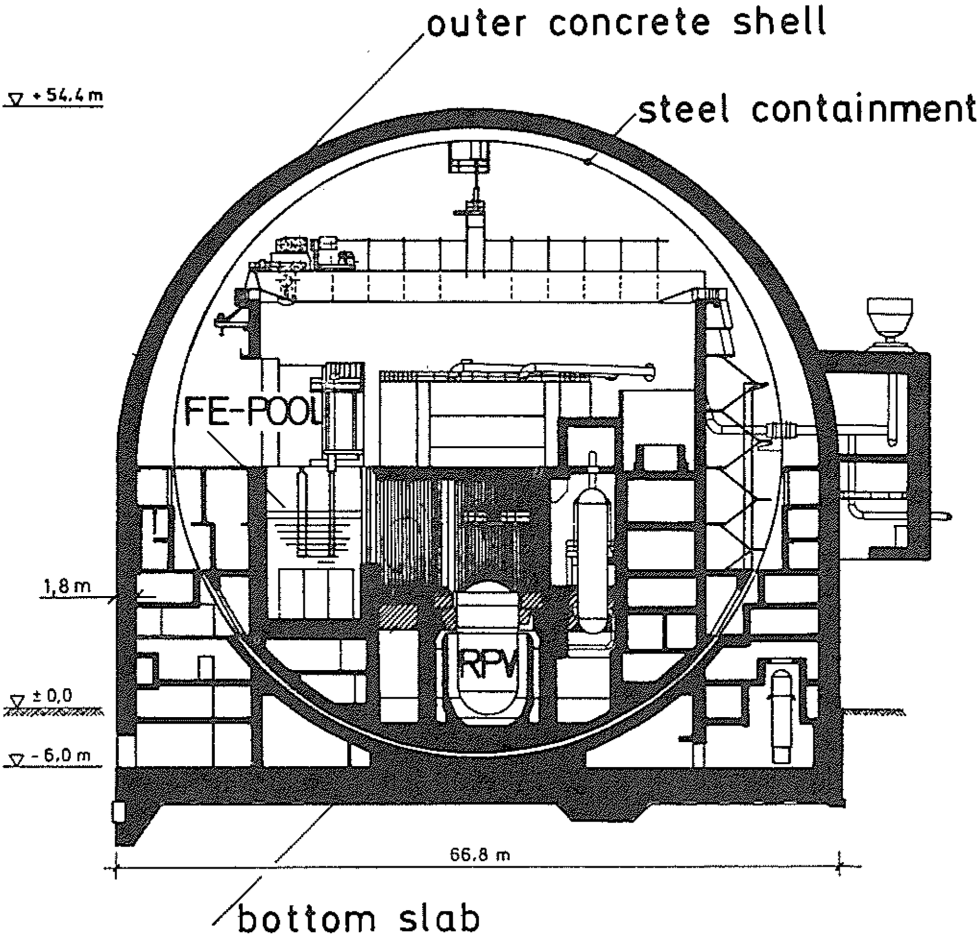

fig. 1 · reactor building for a typical German PWR-Plant (type KWU)

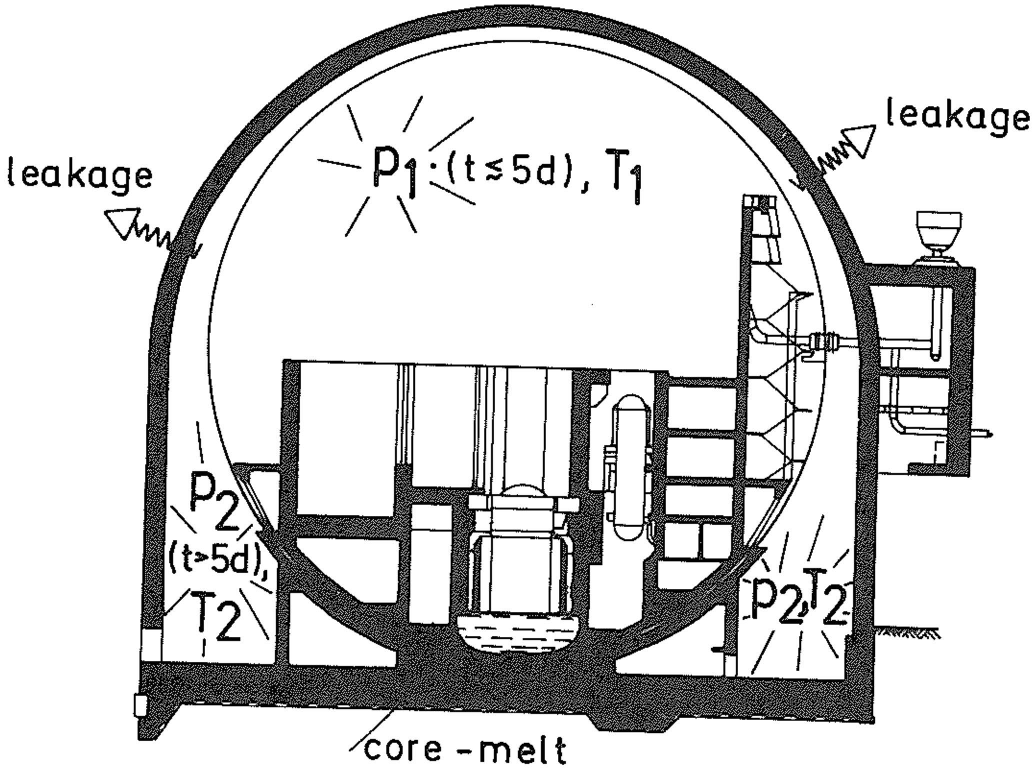

fig. 2 pressure built-up in the steel containment (no leak, Fk 6) according to ref. /1/.

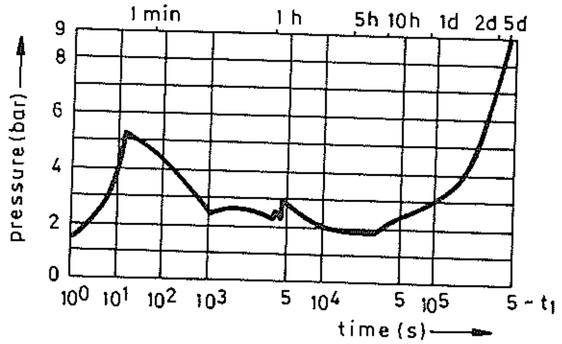

fig. 3 Symbolic presentation of affections on concrete structures