Containment atmosphere stratification during severe accidents Results of HDR and DEMONA experiments

T.F.Kanzleiter
Battelle-Institut e.V., Frankfurt am Main, FR Germany

1 INTRODUCTION

At different time intervals in the course of a severe reactor accident, various amounts of steam and gases are released into the containment atmosphere, which finally results in excessive containment overpressure. The model calculations made for safety analyses often assume that the steam and gases that are released mix completely with the existing containment atmosphere, and that the containment atmosphere remains homogeneous during the further course of the accident. Experiments in large-scale facilities showed, however, that these assumptions in general are not correct and that often an inversely stratified containment atmosphere develops, whose density is lower at the the top than at the bottom of the volume. This means that most of the safety analyses are based on assumptions which are in contradiction with experimental findings. The present paper deals with the stratification phenomena observed and discusses their possible influences on the containment behaviour.

2 CONTAINMENT ATMOSPHERE COMPOSITION

During the course of a severe accident, a containment atmosphere develops which consists of air (initially contained), steam (released) and other gases (released; the most important gas being hydrogen because of its inflammability). As long as the containment pressure increases or at least stagnates, steam condensates continuously at structures, yielding an approximately saturated state of the steam-air-gas atmosphere in most containment regions. Superheated atmosphere conditions can only exist in small areas where superheated steam or hot gas is injected. In case of saturated conditions, the local atmosphere temperature is governed by the local partial steam pressure, the total of the locally varying partial pressures of steam, air, and gas forming the overall containment pressure.

3 MIXING AND STRATIFICATION MECHANISMS, EXPERIMENTAL RESULTS

The local density of an inhomogeneous containment atmosphere varies according to its local steam-air-gas composition, an atmosphere enriched with air being heavier than an atmosphere with a high steam content. Resulting density differentials can lead to natural convection phenomena which tend to produce a stable situation, either homogeneous or inversely atmosphere distribution.

In DEMONA and HDR long-term containment experiments, two major effects were identified, which affect the steam-air-gas distribution of a containment atmosphere:

(1) Injection of a fluid of a density differing from that of the local atmosphere. Possible configurations and resulting effects are depicted in Fig. 1. A completely homogeneous atmosphere can be achieved only in a containment volume without partitions if a low-density fluid (e.g. steam) is continuously injected at the bottom (Case A). All other configurations (B to F) will lead to inhomogeneous atmosphere distribution. Partition walls inside a containment tend to intensify the resulting inhomogeneities (Cases E and F).

(2) Steam condensation at structures leads to steam depletion and air enrichment in the atmosphere boundary layer which, as a result of its increasing density, moves downward and thus causes accumulation of air and of other non-condensable gases in the lower containment regions (see Fig 2). DEMONA experimental results demonstrated that this "diffusiophoretic" effect is strong enough to produce a slight stratification in a single-volume atmosphere during a cooling-down period (no steam injection) following a long homogenisation phase according to Fig. 1A.

Fig. 3 depicts containment atmosphere temperature and steam-air distribution profiles, which were measured in the 60-m-high HDR test facility at different time intervals during a long-term containment experiment. This particular experiment started with a small-leak blowdown covering 1h, followed by natural cool-down of the containment atmosphere. The resulting steam-air atmosphere can be divided into three zones: (1) dome zone with homogeneous steam-air distribution, (2) transition zone in the upper compartmented region with inhomogeneous distribution and remarkable convection effects, and (3) basement zone without steam.

Fig. 4 shows temperature/steam-air profiles measured in the 10-m-high Battelle model containment during a quasi-steady-state DEMONA experiment after a two days' structure-heat-up procedure. The most remarkable result of this particular experiment is that atmosphere stratification can increase in the course of time due to the "diffusiophoretic" effects described above.

4 MODELLING
4.1 SINGLE-NODE CODES

HDR and DEMONA experiments showed that very strong stratification effects exist within a containment atmosphere. A simple homogeneous approach, as it is used by single-node codes for safety analyses, must lead to more or less significantly deviating results, depending on the actual problem:

- In thermodynamic containment calculations, for example the homogeneous approach applied to a stratified steam-air atmosphere results in a calculated structure heat-up which is too high for the bottom regions and too low for the top regions. As most of the containment structures are located in the bottom regions, the total heat transfer to structures is overestimated. This leads to an underestimation of the resulting containment pressure by a calculation using the homogeneous approach.

- For distribution problems, e.g. the distribution of hydrogen or aerosols, the deviations between a homogeneous approach and an actually stratified containment atmosphere are even more evident. As the existence of stratification indicates a lack of mixing mechanisms in the atmosphere, the local concentration of one specific component can significantly deviate from its average value. For example, local hydrogen concentration can reach dangerous values, while the average concentration for the whole containment volume is still below the ignition limit.

4.2 ADVANCED CODES

In principle, the observed atmosphere stratification can be modelled by multi-compartment and 3-D containment codes like FIPLOC (RALOC), CONTAIN and COBRA-NC. Evaluation of the described experimental data has started and, for example, some FIPLOC calculations performed by GRS Munich yielded already very promising results. But a lot of code verification work remains to be done until a state of knowledge is reached that permits the containment atmosphere stratification for a given accident situation to be reliably predicted.

5 RESUME

Experimental results from containment experiments performed in the HDR and DEMONA programmes were discussed. On the one hand, the findings of these experiments can be directly applied to real accident situations in a containment, either in a qualitative or - with coarse approximations - in a quantitative manner. On the other hand, the HDR and DEMONA results provide a sound data basis for verification and further development of computer codes. These codes then can be used to reliably predict the distribution of the components of a containment atmosphere during a severe accident and the resulting consequences for the further course of the accident, or the efficiency of any countermeasures considered.

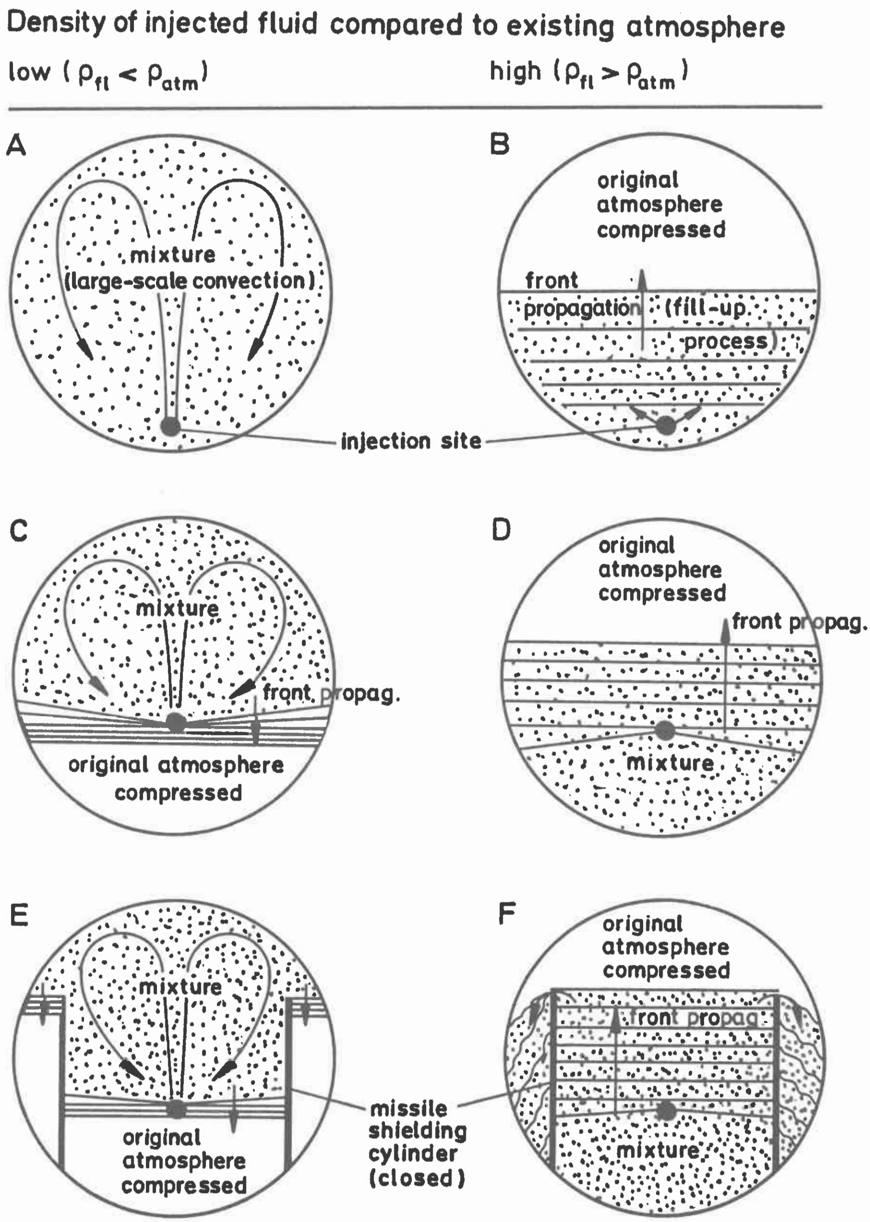

Fig.1: Formation of homogeneous or inhomogeneous containment atmosphere distributions due to fluid injection.

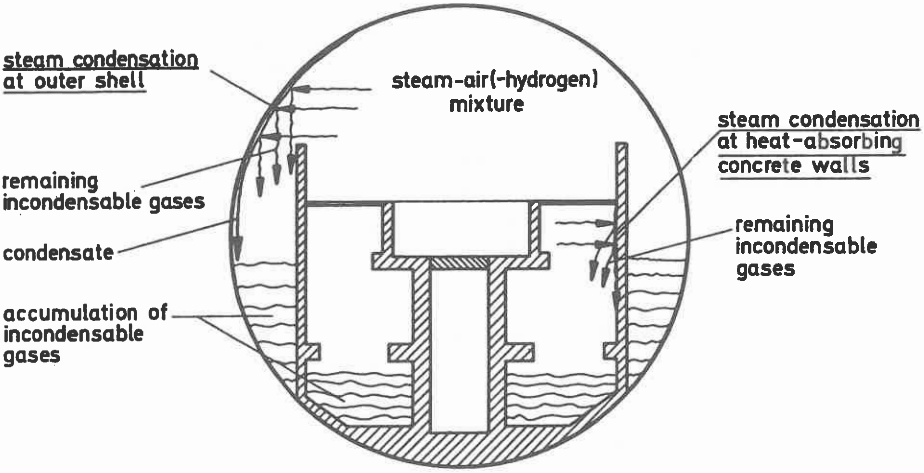

Fig.2: Formation of an inhomogeneous (stratified) containment atmosphere distribution due to condensation effects ("diffusiophoresis")

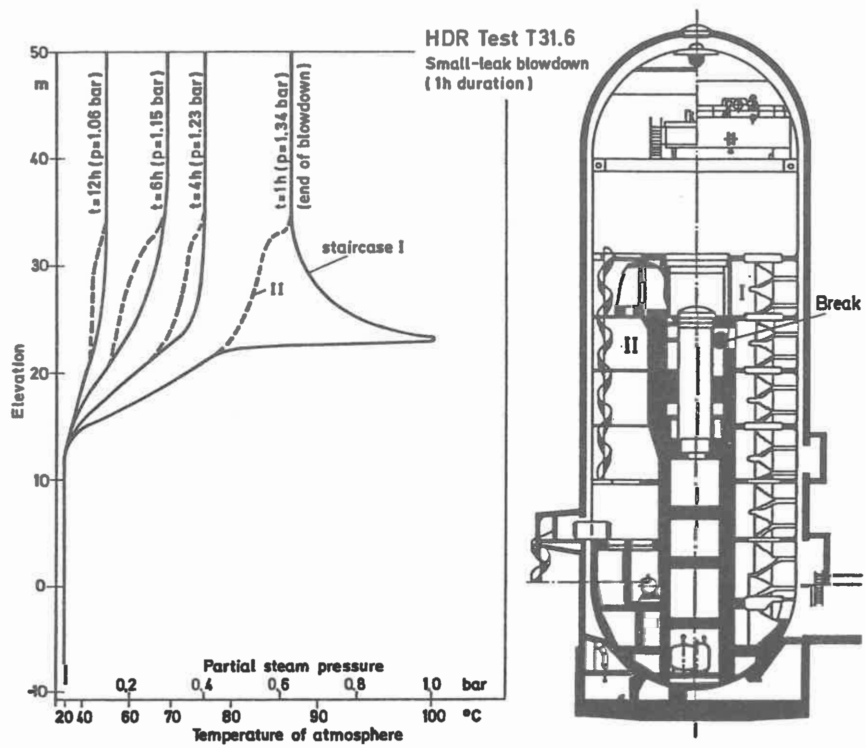

Fig.3: Stratified containment atmosphere in HDR Experiment T 31.6

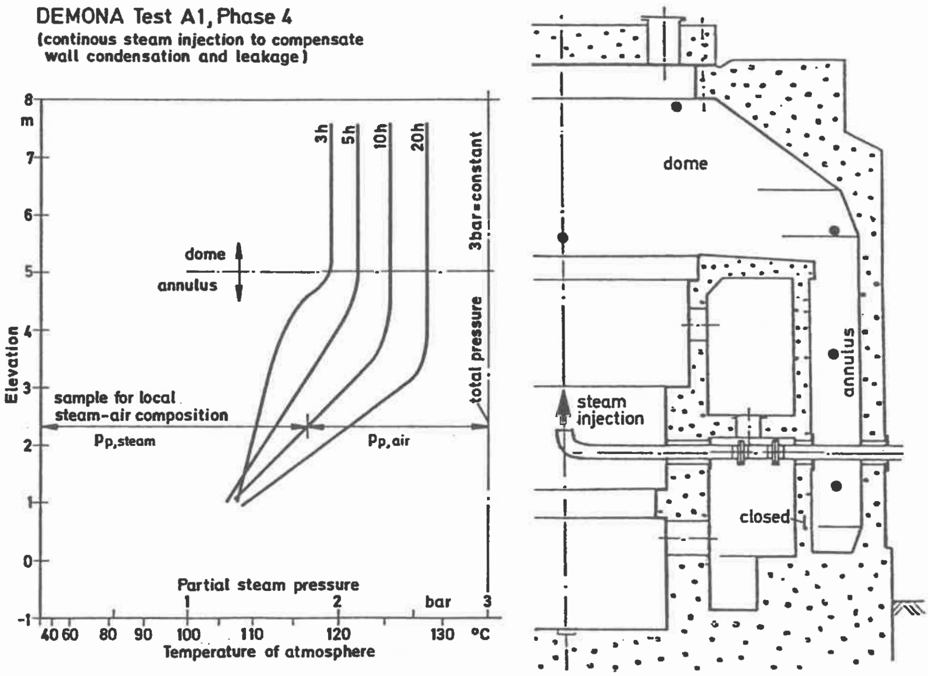

Fig.4: Stratified containment atmosphere in DEMONA Experiment A 1