HDR Hydrogen Distribution Test After Large LOCA

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ABSTRACT
During Phase II /1/ of the HDR Safety Program, a preliminary H_2-distribution test T31.5, was performed in December 1987 connecting the objectives of the International Standard Problem (ISP) 23 /2/ and the purpose of obtaining a first set of experimental data for long-term gas transport behavior in a real-scale multi-compartment facililty under severe accident conditions in the containment.
The preliminary experiment was needed also for reliably planning the major H_2-distribution test series E11.1 through E11.5 to be carried out between May and August 1989 /3/.
The paper presents the experimental and computational results of the gas distribution and their influencing atmospheric containment conditions.

INTRODUCTION
The HDR facility, with a total free volume of 11.300 m^3, consists of a steel shell 60 m in height and 20 m in diameter and a surrounding secondary concrete shell. The steel and the concrete shells are separated by an annular gap of 0.6 m width. The facility is subdivided into 69 compartments containing a large amount of steel structures and is interconnected by 230 flow paths.
The break compartment is connected via two long vertical flow paths along the staircase (90°) and spiral staircase (270°) with the dome region (see Fig. 3).

EXPERIMENTAL PROCEDURE
Once a realistic temperature gradient was established in the containment as initial and boundary condition resulting from the large break LOCA, the steam injection starts 21 min after blowdown begin for 15 min. Immediately after shut-off of the steam injection, the H_2/He-mixture was released at the same position as the break into the containment. The mass flow rates are shown in Fig. 1 and 2, respectively

EXPERIMENTAL AND COMPUTATIONAL RESULTS
As can be inferred from Fig. 3 and 4, a temperature stratification pattern develops in both flow paths with some differences in local details. The highest temperatures are concentrated in the spiral staircase more closely to the break subcompartment, whereas in the staircase this region extends over a larger region of the height. Clearly visible are the rather fast temperature decays after the blowdown ends prior to the steam release. Yet, a sizable temperature gradient of at least 50°C remains between lower and upper parts of the containment. However, with some local exceptions

(break compartment, sump), the temperatures are rather homogeneous from at least the level of break subcompartment on upward. It is interesting to note, that the additional steam injection for over 15 min barely disturbs the homogeneity of the temperature in the containment at this time . The gas mixture injection starting at 35 min into the transients leads also to a gradual cooling of the containment atmosphere. The stratifications in both flow paths diminish gradually with time with the exception of a localized region around the break compartment at the level of +26 m where higher temperatures persist over the total of 20 hours measurement time.

The H_2/He mixture injection starts at 35 min into the transient and lasted for 12 min. The axial profiles for the hydrogen concentrations along the two major flow paths are given in Fig. 5 for 40 and 60 min.

As seen from Figs. 5 and 6 the major portion of the released H_2 exits the break subcompartment into the spiral staircase and from there reaches the upper dome region. Highest concentrations in both major flow channels start to build up with appreciable time delay and reach their maximum long after injection stopped. Also worthmentioning is the fact that levels below the injection position in the containment are affected, obviously by virtue of diffusion. The extent to which lower levels are penetrated by the hydrogen is quite different in both flow paths as is obvious from the figures. Also, the transition region between the staircase and the dome region (sensor CG 0431) is characterized by a distinct spatial H_2-depression, e.g. a region of lower concentration is encapsuled between regions of higher concentrations. By all accounts, a pronounced, large H_2-concentration gradient exists along both flow paths at 60 min as seen from Fig. 5.

Fig. 6 represents the evolution of the H_2-concentration for some selected hydrogen sensors along the staircase. From this and the foregoing figure some interesting results are observable. First, the highest concentration, persisting in the dome area, remains undiluted for over 200 min. Then, first gradually, somewhat later rather abruptly, a substantial decrease in concentration starts, obviously transporting hydrogen to lower levels in the containment, resulting in higher concentrations there, than in the upper regions. Although, there is clearly a homogenenization throughout that region visibel, even at the end of measurement time, concentrations are slightly higher at lower than upper regions. This effect may be attributable to the measurement principle of the H_2-sensors which determines the volumetric concentration within the ternary diagram (air-steam and H_2). In the lower containment region the steam fraction is extremely low compared to the upper regions.

Blind post-test predictions were performed by a variety of national and international institutions using a broad spectrum of different computer codes for hydrogen distribution analysis. Participating codes were: COBRA-NC, CONTAIN, HECTR, HMS, MELCOR, RALOC and WAVCO covering the whole spectrum of internationally known models for two-phase flow and gas transport in nuclear reactor containments. Nodalizations ranged from 16 up to 7031 computational cells/nodes, and the problem times covered were 1 hour up to 20 hours, respectively.

The comparisons of the computational results are presented in three categories of plots: American pre-test computations (60 min), German pre-test computations (1000 min) and various post-test computations.

Two distinct containment regions are chosen for the purpose of comparisons out of the immense amount of available experimental and computational results. These are selected at the axial elevations of + 28 m and + 10 m, respectively.
The temperatures (see Figs. 7 to 12) in the upper region of the facility show dependent upon the codes and models applied over- and underpredictions of the order of + 20°C and - 10°C, respectively. These differences may be attributed to the different modeling schemes for the heat slabs as well as to the different correlations used for the predictions of the heat transfer coefficients. In the lower region of the containment, the calculated temperatures are generally overpredicted by up to 30°C. Too coarse nodalizations of the middle and lower containment regions as well as the fact that steel shell and annular gap between steel shell and outer concrete are not modelled at all may be responsible for these overpredictions.
The comparisons between measured and computed H_2-concentrations (see Figs. 13 to 18) show overpredictions for positions above the break/injection location. This is due to the H_2-concentration sensor technique because of the time delay involved in initiating the catalytic process. After this initial period, the computed H_2-concentrations are qualitatively in good agreement with the measured data with a few exceptions. Especially in the lower containment region, H_2-concentrations are partly overpredicted by substantial amounts. These overpredictions are, besides other effects, also the results of the noted differences in the temperature predictions cited above, because the hydrogen distribution in the long-term largely depends upon the distributions of temperature and steam/air.

CONCLUSIONS

The first, preliminary hydrogen distribution experiment T31.5 in the large-scale test facility HDR has demonstrated the feasibilities of procedures and measurement techniques and thereby provided valuable data for planning the major HDR-Hydrogen Distribution Test Group, E11 (May - August 1989).
Important informations were obtained about H_2-concentrations under realistic atmospheric containment conditions after LOCA indicating that initial local concentrations differences between spatial containment regions cease and homogenize.
The available computational methods are generally capable to predict the observed phenomena. However, improvements deem necessary in the area of modelling/nodalization which is in the responsibility of the potential code user.

REFERENCES

/1/ HDR-Safety Program
- General Program Phase II -
HDR-Report 05.25/86, Jan. 1986

/2/ H. Karwat
Preliminary Comparison Report ISP 23
March 1989

/3/ HDR-Safety Program
- Overall Program Phase III -
Oct. 1988

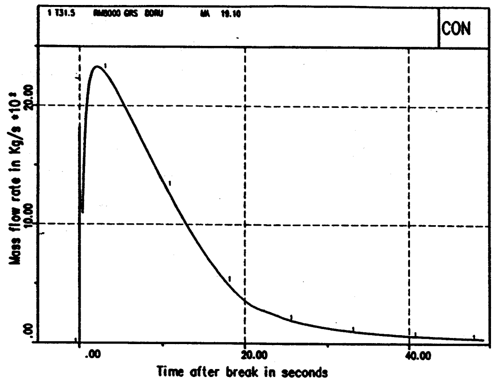


Fig. 1 Blowdown Mass Flow Rate

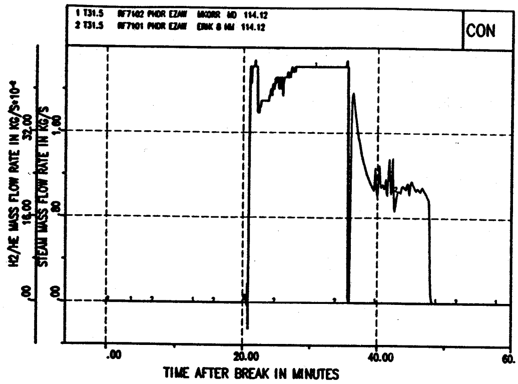


Fig. 2 Additional Steam and H2/He Mass Flow Ratestions

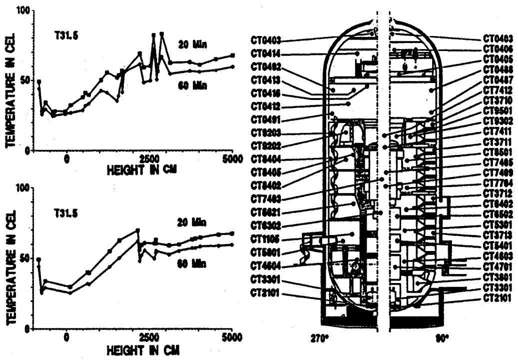


Fig. 3 Temperature Profiles Staircase and Spiral Staircase

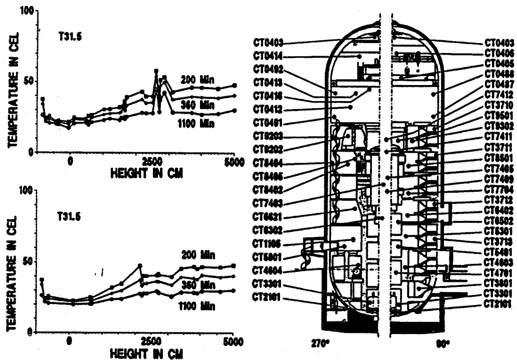


Fig. 4 Temperature Profiles Staircase and Spiral Staircase

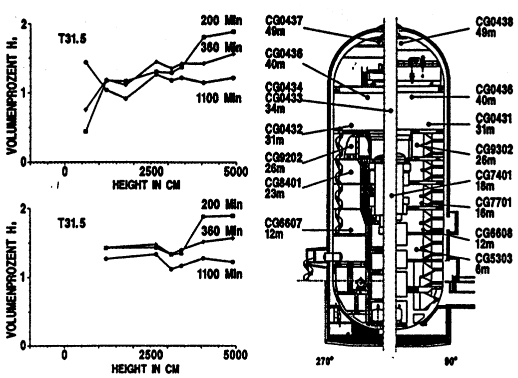


Fig. 5 H2 - Concentration Profiles Staircase and Spiral Staircase

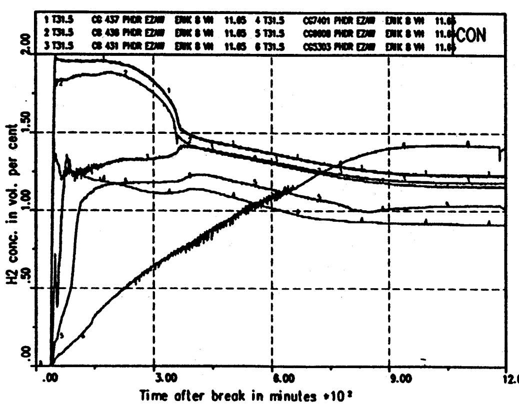


Fig. 6 Selected H2 - Sensors Along Staircase

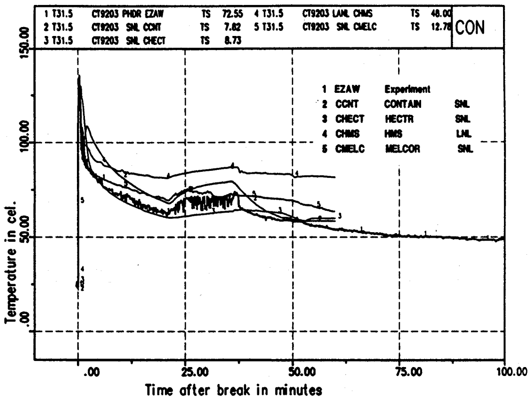


Fig. 7 Temperature at +28 m US - Predictions

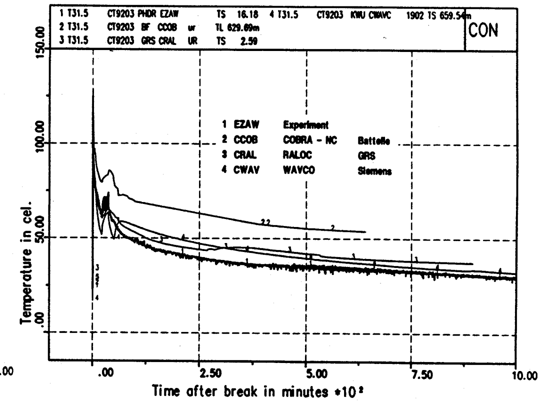


Fig. 8 Temperature at +28 m German - Predictions

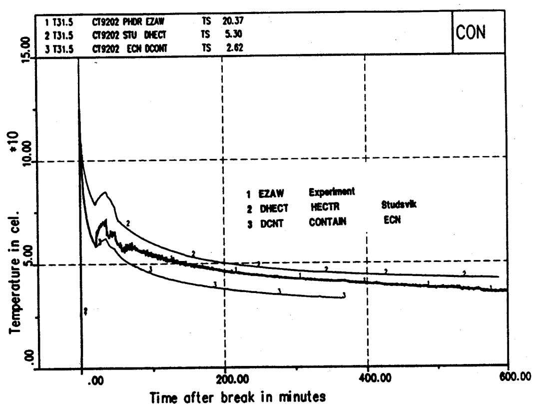


Fig. 9 Temperature at +28 m Post Calculations

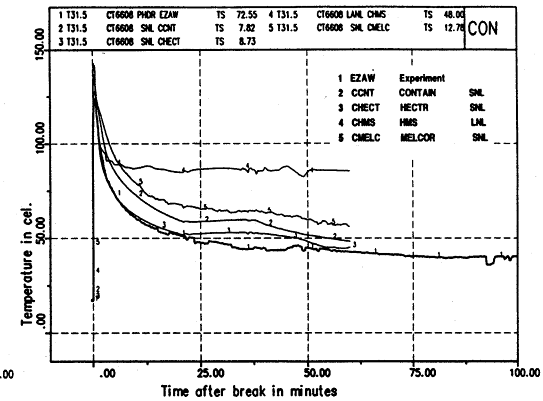


Fig. 10 Temperature at +10 m US - Predictions

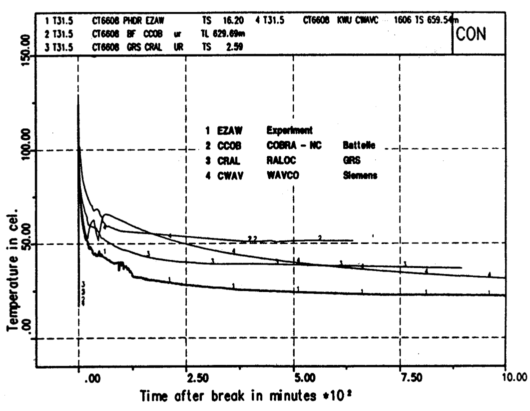


Fig. 11 Temperature at +10 m German - Predictions

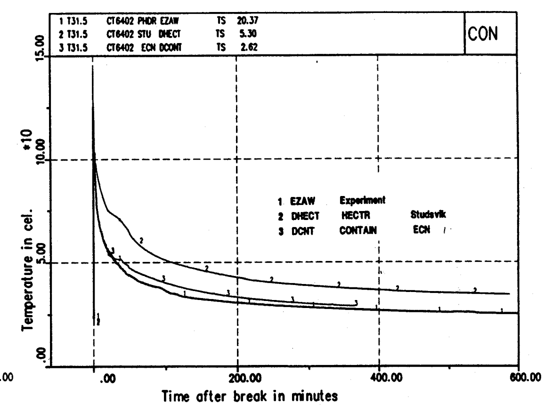
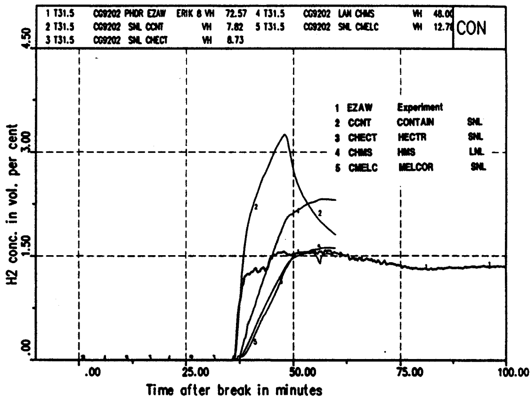


Fig. 12 Temperature at +10 m Post Calculations



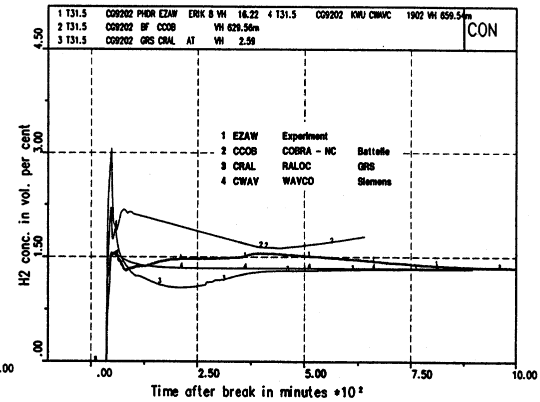
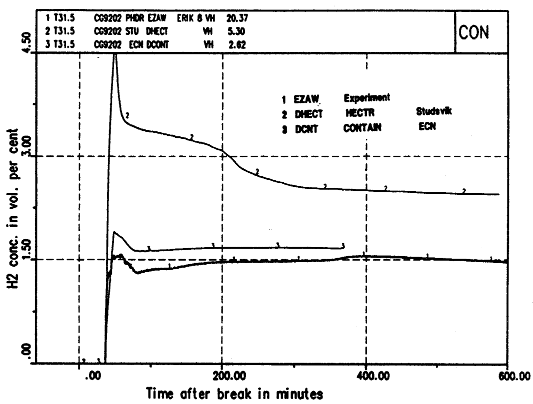


Fig. 13 H2 - Concentration at +28 m US - Predictions

Fig. 14 H2 - Concentration at +28 m German - Predictions



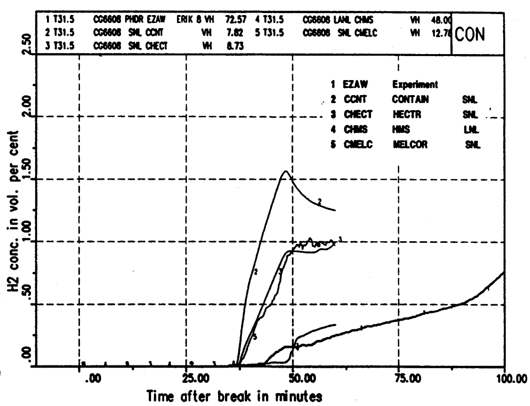
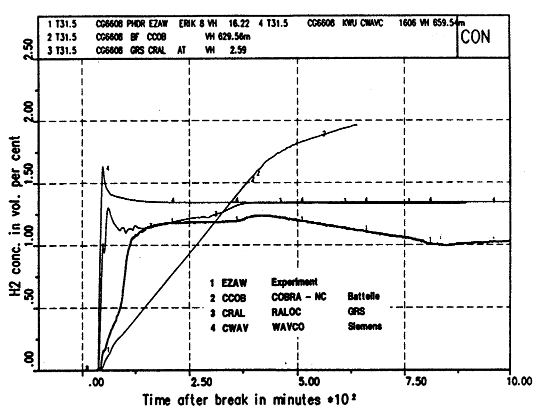


Fig. 15 H2 - Concentration at +28 m Post Calculations

Fig. 16 H2 - Concentration at +10 m US - Predictions



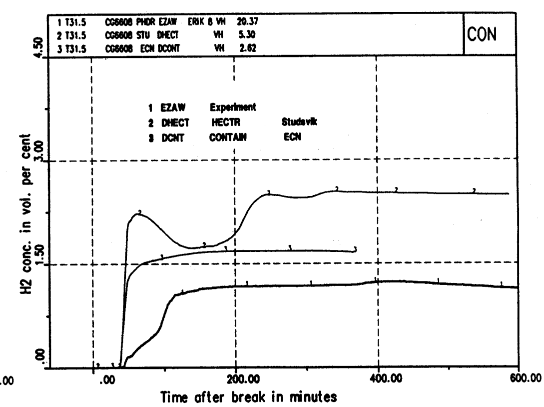


Fig. 17 H2 - Concentration at +10 m German - Predictions

Fig. 18 H2 - Concentration at +10 m Post Calculations