Hydrogen Distribution Tests under Severe Accident Conditions at the Large Scale HDR Facility

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ABSTRACT

The E11 tests series covered a combination of important issues dominating the physical phenomena controlling the H_2-distribution mechanisms, namely: large-scale, multi-compartment geometry with large-sized dome volume, high gas release rates, multiple steam and gas injection phases at different axial positions and examinations of the efficiencies of mitigative system features including the impact of external sprays at the top of the dome.

1 INTRODUCTION

The reliable knowledge of the temporal and spatial distribution of non-condensible gas concentrations, especially H_2 in multi-compartment geometries is necessary to design and install mitigative features.

On the basis of the experiences gained from the previous, DBA-oriented test T31.5, with respect to experimental, measurement and computational aspects, a complete, major test group E11 was designed and performed in the framework of the HDR Safety Program Phase III (1988 - 1992) during the summer of 1989. The objectives of E11 have been outlined in /1/. An overview of the five test procedures is given in /2/.

Experiments E11.2 and E11.4 were chosen for two computational PHDR-Benchmark Exercises in the contex of blind post-test predictions with broad international participation applying the majority of know computer codes /3/.

2 TEST PROCEDURES

Figs. 1 and 2 summarize the details characterizing the experimental procedures for Experiments E11.2 and E11.4.

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3 MEASUREMENT SYSTEMS

A total of 700 sensors were applied during the experiments of test group E11. Great care was exercised to determine the gas concentration and composition of the atmosphere at 45 positions.

The experimental results shown in the following chapter are primarily data of the sensors depicted in Figs. 3 and 4. Other sensors not shown in these paper are explained and presented in the complete measurement plan /1/ for test series E11.

4 EXPERIMENTAL RESULTS

During accidents with small LOCA's or leaks pronounced and sustained temperature and steam concentration gradients develop dependent upon the axial elevation of the break or leak. Figs. 5 and 6 are shown temperatures at various elevations for the experiments E11.2 and E11.4 respectively,in order to demonstrate the different behavior of both tests: E11.2 stratified (break at 23.5 m) and E11.4 (break at 3 m) nearly homogeneous. At the end of the heatup period a maximum of 130°C is reached by Test E11.2 and 954°C by E11.4. Similar observations can be made fora the steam concentrations (compare Figs. 7 and 8) for both tests E11.2 and E11.4 with maximum of 90 and 50% by volume, respectively.

Non-condensable gas releases into a stratified or homogenized containment atmosphere result in similar distribution of concentrations (compare Figs. 9 and 10).

The gas was injected in the time interval between 740 and 772 mins for E11.2 and for E11.4 double: first between 2083 and 2114 mins and second between 2183 and 2200 mins.

The additional release of steam at low axial elevations (e.g. E11.2 at 3 m between 773 and 959 mins) in the containment can break up stratification patterns without leading to homogeneously mixed conditions (see figs. 5 and 7). The steam plume sweeps the gas into the dome region, thereby reducing gas concentration along its flow path (see Fig. 9).

External spray on top of the steel dome decreases dome temperatures and steam concentrations as wenn as containment pressure by about 0.5 bar and 0.25 bar for E11.2 and E11.4, respecitively. Vigorous condensation inside the dome during the initial spray phase of E11.2 results in drastic spiking of gas concentration in the dome (25% by volume) within a time period of 30 mins (compare Figs. 5, 7 and 9).

5 GAS AND TOTAL ENERGY BALANCE

If one subdivides the containment into 42 discrete volumes and allocates a measured gas concentration in each one, then assuming that the gas in each discrete volume is homogeneously distributed, the mass of gas in each volume can be determined.

The sum of the individual masses of gas gives the total amount of gas in the containment. Figs. 11 and 12 show a comparison between the injected mass of gas and that contained in the containment; this indicates an integral difference of +2.6% for E11.2 and +2.1% for E11.4. This difference is mainly due to the assumptions made and to a certain inertia of the humidity sensors, which do nor react quickly enough to rapid changes in the atmosphere.

The total energy balance (see Figs. 13 and 14) with overall uncertainties of 5 and 3,8% for E11.2 and E11.4, respectively demonstrate the high quality of the measurements.

6 CONSLUSIONS

8 hydrogen distribution tests with different accident sequences were carried out. It can be collectively stated, in spite of the immense number of over 700 sensors used, that the plant and measuring techniques functioned excellently.

During accidents with small leaks - dependent on the location - pronounced and sustained temperature stratifications occurred in the containment. The relative stable separation into "cold" and "warm" zones caused equally stable hydrogen stratifications with an increased concentration under the dome and lesser concentrations in the lower regions.

The accident management measures examined (external spray, venting) could not decisively impair these stratifications. By E11.2 the pressure drops in the containment due to external spraying amounted to 0.5 bar in approx. 4 hours, whereby the gas concentration in the dome-increased drastically during the first 30 minutes.

7 REFERENCES

/1/ Valencia, L.; Wolf, L.: Design Report for Test Group E11 Hydrogen Distribution Experiments of HDR, PHDR Working Report 1o.004

/2/ Valencia, L.; Wolf, L.: Overview of First Results on H_2-Distribution Tests at the Large Scale HDR-Facility, 2nd Int. Conf. on Contaiment Design and Operation, Toronto Oct. 14-17, 1990

/3/ Wolf, L.; Valencia, L.: Results of the PHDR Computational Benchmark on Hydrogen Distribution Experiments E11.2 and E11.14. Workshop on hydrogen Behavior and Mitigation in Water-Cooled Nuclear Power Reactors, Brussel March 4-8, 1991

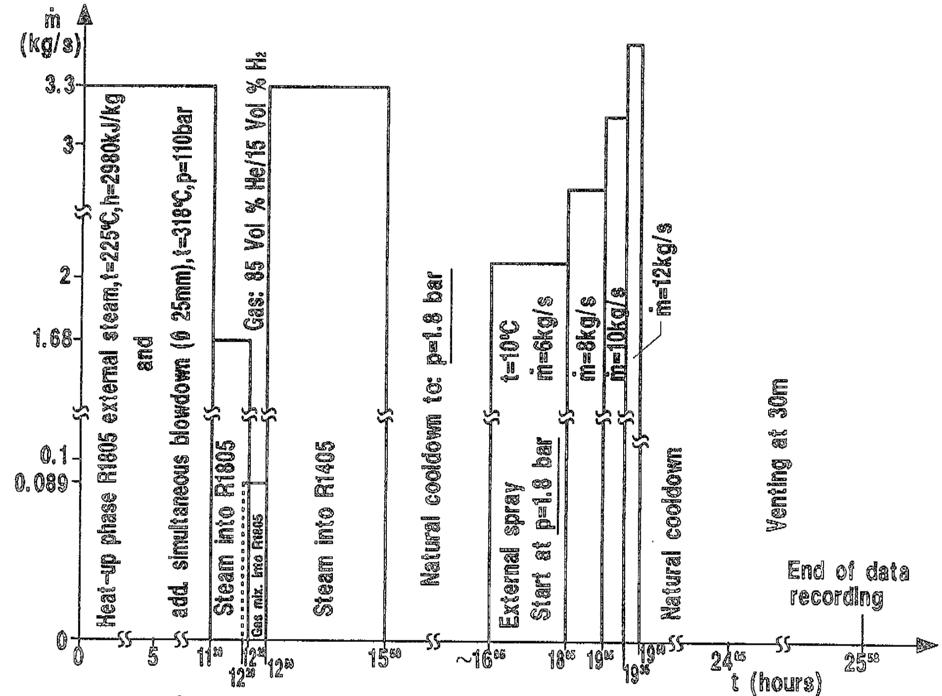

Fig.1: Experimental Procedure for E11.2

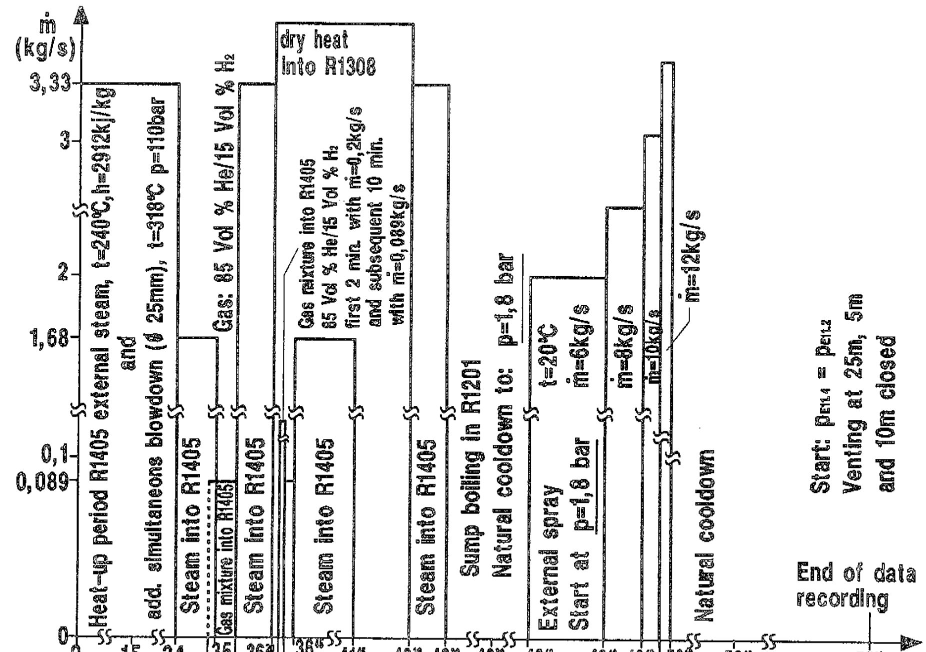

Fig.2: Experimental Procedure for E11.4

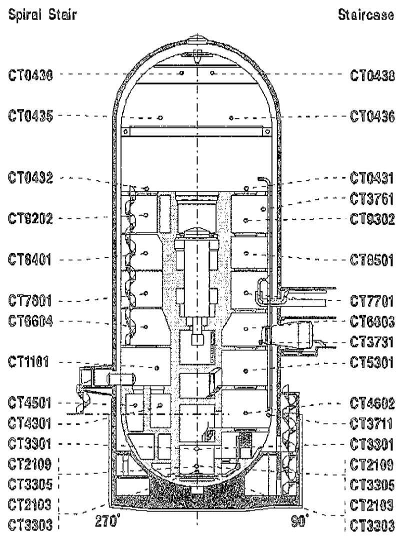

Fig.3: Positions of Thermocouples

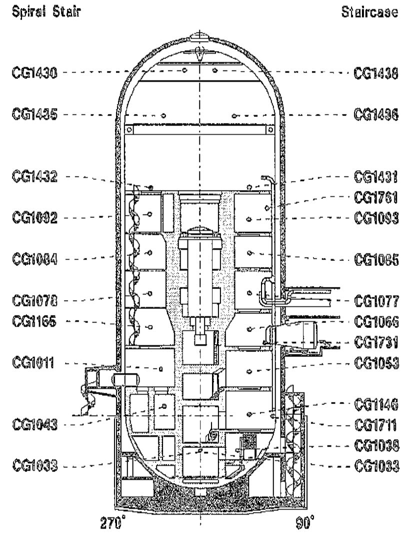

Fig.4: Positions of Gas Concentration Sensors

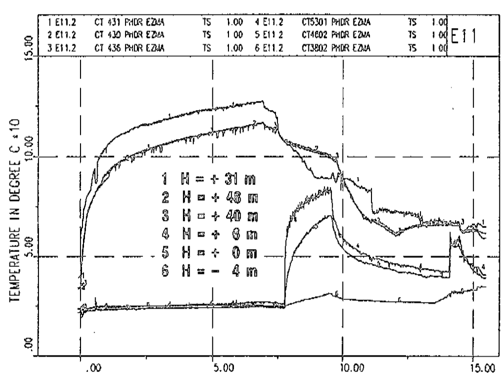

Fig.5: Temperatures along Staircase, Test E11.2

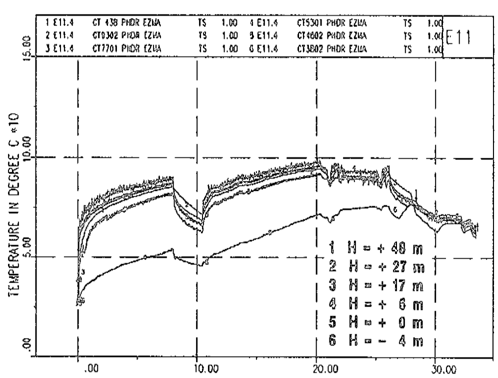

Fig.6: Temperatures along Staircase, Test E11.4

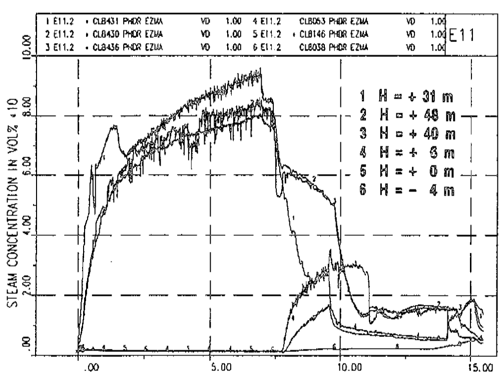

Fig.7: Steam Concentrations along Staircase, Test E11.2

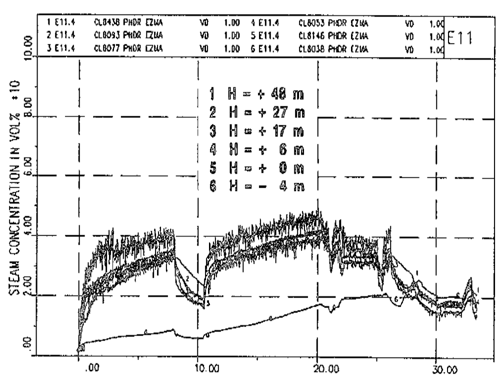

Fig.8: Steam Concentrations along Staircase, Test E11.4

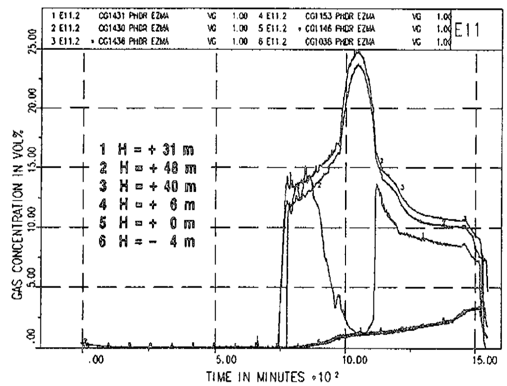

Fig. 9: Gas Concentrations along Staircase, Test E11.2

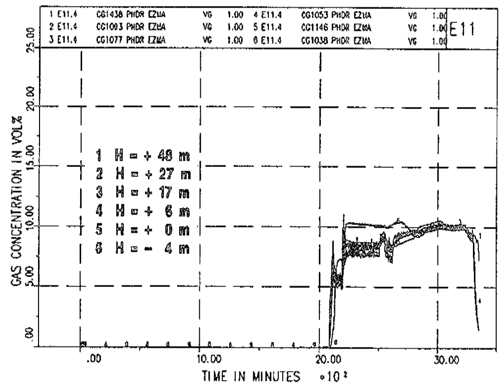

Fig. 10: Gas Concentrations along Staircase, Test E11.4

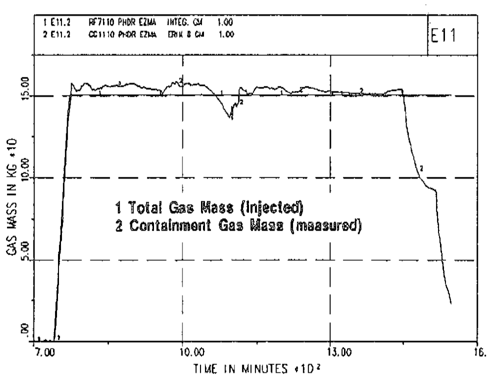

Fig. 11: Comparison of Injected and Measured Total Gas Mass, Test E11.2

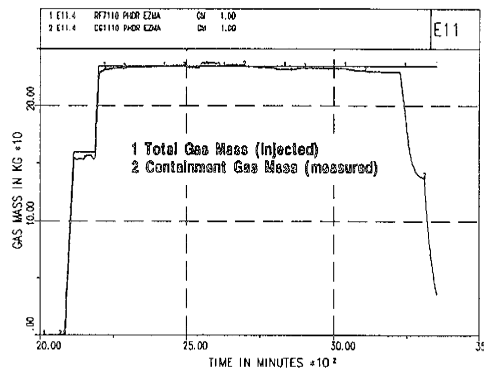

Fig. 12: Comparison of Injected and Measured Total Gas Mass, Test E11.4

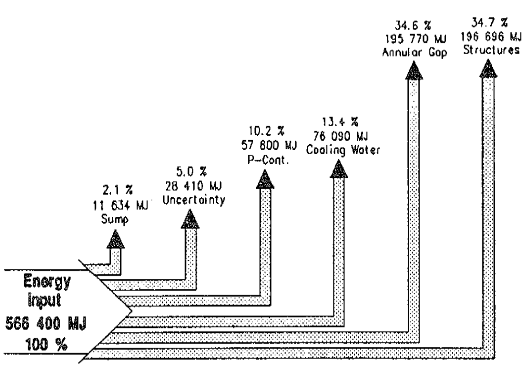

Fig. 13: Energy Balance for Test E11.2

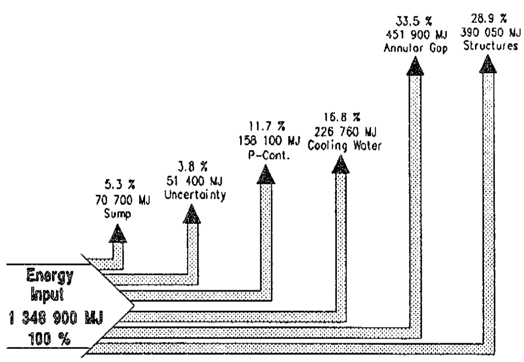

Fig. 14: Energy Balance for Test E11.4