Fire Code Assessment During HDR Experiments

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ABSTRACT

Fire is one of the last problems in nuclear safety seen from the code side. Codes for fire prediction are normally involved in post calculations of convectional fires, with the smoke escaping through doors, windows, ceiling hatches. The fire situation inside nuclear power plants is very different to this conventional scenario.

1. INTRODUCTION

Fire is one of the last problems in nuclear safety seen from the code side. Codes for fire prediction were normally developed for post calculations of conventional fires, with the smoke escaping through doors, windows, ceiling hatches to the environment. The fire situation inside the closed containment of nuclear power plants is very different to this conventional scenario (Figure 1). Predicting the situation of such a complicated

system needs systematic code assessment in comparison with measured data.

The HDR, an old NPP of 100 MWth is an impressive example of such a complicated area (Figure 2). This used for nuclear safety measures since 1975, gave the opportunity to analyze different fire situations inside a closed containment with extended sensors installations throughout the plant and to compare these measures with fire code results describing the same situation.

Figure 1 Convection in multiroom configurations.

2. EXPERIMENTAL UPSET

The HDR-facility with about $-11,000$ m³ free volume, partitioned into about 62 compartments, equipped with components, pipework, concrete walls, etc. is a great step towards reality within the framework of integral fire experiments. The HDR containment is surrounded by a closed steel shell. It is 60 m high and 20 m in diameter and internally divided structures into 62 compartments. Various items of machinery are still installed. Detailed data regarding the individual chambers dimensions and volumes, the been documented. This data is constantly updated and used for calculations of plant behavior, during fire and other safety related loading of the facility.

The first tests starting with gas and wood crib fires were to study the behavior of the facility at low energy output rates.

Figure 2 HDR longitudinal cut with fire areas.

Figure 3 Experiment matrix.

Figure 4 Code verification procedure.

Figure 3 shows the experimental fire programme. During the following oil fire tests improved knowledge of temperature; fume and soot effects on a complicated large scale test facility was gained. These results encouraged to conduct high power oil pool and cable fire in the plant.

So data were produced for different fire situations taking into account the combustibles as well as room ventilation properties.

3. FIRE CODE HISTORY

NPP fires as Rocky Flat or Browns Ferry stimulated work of nuclear plant fire safety assessment and design.

Several PRA studies of NPP's showed that important contribution to the overall risk of radioactive release could be attributed to fire.

On former nuclear power plant designs, the major defense against fire was physical segregation of the safety systems to ensure that sufficient plant remains undamaged by fire to allow all the necessary safety functions to be carried out. This implies that for safety justification purposes it is only necessary to demonstrate that principal segregation barriers are adequate against fire attack.

But providing answers to fire safety problems in nuclear power plants a code should determine the physical parameters which influence the development of fire as well as the distribution of fire products throughout the whole plant.

4. FIRE CODE ASSESSMENT

Since 1982 assessment of fire hazards has been done by carrying out experiments and developing various fire codes for nuclear power plants in Germany. Starting with standard fire tests; small scale and separate effects tests the HDR Experiments are the next logic

step to real plant behavior (Figure 3).

The fire tests carried out in the HDR plant can be considered as large scale tests and as an important step to transferability of fire impacts to real plants (Figure 4).

In the course of the tests a multitude of measured values with defined boundary conditions have been recorded and processed; they are now available as a basic data set for evaluation.

A code predicting fire inside the containment of a NPP is confronted with:

- a closed shell to the outside
- forced ventilated rooms
- loops inside the plant, formed by the geometric properties of stairs, hatches, channels between rooms, floors etc.

Learning from the nuclear safety code assessment approach which is successfully running since years, the HDR fire research program started from the beginning with different code types and their different levels of development in a competitive comparison (Figure 5) to estimate the weak and strong points of the different approaches used.

A code which describes both; the effects of fire on the nearby surroundings and the aspects important to areas far away from the fire would be very useful.

For the first time world wide different codes were forced to calculate the same experiment, and to discuss the results between experts.

Zone models (Figure 6) were developed for conventional preventive fire protection. They were able to describe single fire rooms and were mainly used to calculate the time dependent temperatures, and the energy and mass flux in structures and ventilation openings, classifications which are used in the Federal German Fire Standards.

Examples of used zone models are:

Figure 5 Types and categories of codes applied.

Figure 6 Zone - model HAL.

Figure 8 Field model Phoenix VTT.

Figure 7 System code RALOC.

Technical University of Braunschweig
Code DOB
University of Kassel (G)
Code MRFC
Technical Research Center VTT (Finland)
Code CFC
Siemens/KWU (G)
Code TEMP

System codes (Figure 7) were developed initially to describe the post-accident atmosphere and hydrogen distribution when loss of coolant occurred in LWR containments. Using the multinode approach, a given building is represented by a finite number of zones in which energy, mass and momentum balances are calculated. The system codes were prepared to describe multiple fire room behavior. Initially, the codes were unable to describe fire development; because of their lacking fire source term.

Examples of System codes are:

Gesellschaft für Reaktorsicherheit (G)
Code RALOC
Los Alamos National Laboratory (USA)
Code FIRAC
(system code with field modeling items)
Battelle Institute (G)
Code COBRA-NC

Field models describe the impact of fire, i.e. energy; mass balance; temperature and flow properties, in a 2D or 3D way (Figure 8). However, their use in multiple room scenarios poses problems, concerning the necessary nodalization of realistic geometries.

Examples of field models are:

Technical Research Center of Finland
Code PHOENICS
Sandia National Lab. USA
Code NOTRE-DAME

For not to ease this competition, initial parameters were changed from one experiment to the next as:

- size and level of fire compartment inside the plant. (Figure 2)
- Fuel source: gas/wood/hydrocarbon/cable
- Size of fuel source and its energy output ; as pool fire dynamic; constant by feeded pool ; cable trays etc.
- changing ventilation arrays etc.

So the participating institutions had to evaluate their codes in close comparison with measured values and to rearrange their code modules. A set of blind preliminary calculations as well as open post test calculations gave them the opportunity to test the worthiness of their program-changes.

It is attempted to describe for several groups of tests the progress of verification and to specify improvements achieved. In this context, weighting of the fire phenomena during the tests should be mentioned which led to a classification by:

- requirements for describing the combustion behavior and the energy release
- requirements for describing the fire induced mass and energy transport in multi-compartment chains
- requirements for describing the behavior of ventilation systems and exhaust filters during fire inside the plant.

Starting from the comparison of measurement with calculation a preliminary qualitative code evaluation was performed [1]. Critical of evaluation are the accuracy of computation, the scope of information obtained, the expenditure spent on model elaboration as well as the necessary computer running times.

5. CODE ASSESSMENT RESULTS

There are lessons to be learned up to now from these 4 years of code evaluation and assessment.

Comparison of code is urgently needed, but only possible if there is a set of reference points throughout the plant, which all partner have to calculate or endless discussion about results will arrive.

Of the same importance is to create one input parameter set for all participants to ease the discussion of results. Even then there was enough scientific freedom to get a broad data band.

Factors affecting the reliability of model predictions are stated in Figure 9.

All these factors can only be found when running a code on different scenarios; fire problems etc. and in comparison with measured results as well as code/code results.

Factors affecting the Reliability of Model Predictions

- Uncertainty due to improper definition of the assessment problem
- Uncertainty due to the improper formulation of the program module
- Uncertainty involved in the formulation of the model
- Uncertainty inherent within the estimation of parameter values
- Calculation and Documentation errors in the production of the result

Figure 9 Factors affecting model prediction.

Up to now all code systems have reached a certain evaluation goal.

The zone-codes are no longer one-room models. They succeeded to calculate up to 10 interconnected zones with sufficient accuracy.

The system codes have implemented fire source term-modules in their fluid dynamics models. They learned to adapt optimal node size into the code and to reduce computer running times.

The field models are confronted with the mapping of real HDR-Geometry into their computer readable equipments.

Future evaluation has to solve such remaining open issues in fire code verification as:

- dynamic fire source term prediction
- dynamic gas components – and smoke density development and smoke movement
- aerosol distribution and depletion throughout the plant
- filter behavior and closure time
- interaction of fire and surrounding walls

The implementation of these still open issues will help to encircle still missing thermodynamic phenomena important for calculation.

An extended discussion between experts is also necessary concerning:

- the sensitivity of parameters: input/trimming
- the sensitivity of physical formulas
- the sensitivity of code mathematics
- necessary accuracy of code results to problem.

The last point was already discussed by the involved institutions leading to the following conclusions. The fire area can be

area	specific item	accuracy	criterion
near field	temp. hot gas; plume etc. temp. structure pressure	$\pm 15\%$ $\pm 10-15\%$ $\pm 20\%$	main aspects
far field	temp. gas temp. structures pressure difference gas concentrations aerosols	$\pm 20\%$ $\pm 10-15\%$ $\pm 20\%$ $\pm 15-20\%$ $\pm 20\%$	fire relevant aspects
near field	fire properties gas layer	$\pm 30-50\%$	physical consistence of codes
far field	energy and mass flow velocities gas layer		secondary aspects

Figure 10 Accuracy pattern for calculations prediction.

divided into a near field and a far field with differing accuracies as to be seen in Figure 10.

The future code verification process should include an analysis of all involved codes at the start and end of the ongoing evaluation phase due to:

- code modeling and definition
- code prediction of fire phenomena
- open issues

to demonstrate the evaluation progress. Comparison of existing analytic approaches as the US-code analysis (e.g. Mittler) with HDR methodics will be helpful too.

After having solved these problems more practical requirements are to be concerned as:

- the availability of codes to Engineers including a sufficient and available code description.
- assessment of codes in national and international bench-mark exercises.

6. CONCLUSIONS

Theoretical and experimental work done so far led to a better understanding of the fire phenomena and of code validation. The developments and means of input data improvement which are still necessary to safety the requirements made on the codes, e.g. by a change in methodology and a different scope of measurements, are indicated and discussed.

The fire code assessment work has got new impulses from nuclear problems. Now these codes are even worth to be checked on

new scopes of application back in the conventional fire field.

All these statements show the necessary to work in future on fire codes as hard as done in the past.

It is too much work for one institution so national and international discussion and support will be welcome, as initiated with the smirt seminars already.

7. References

- [1] Codebewertung der bei HDR-Brandversuchen eingesetzten Rechenverfahren; GRS-A-1639
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