Innovative Approach to Modeling Accident Response of Gravel Gerties

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Recent safety analyses at nuclear explosive facilities have renewed interest in the accident phenomenology associated with explosions in nuclear explosive cells, which are commonly referred to as “Gravel Gerties.” The cells are used for the assembly and disassembly of nuclear explosives and are located in the Device Assembly Facility (DAF) at the Nevada Test Site (NTS) and at the Pantex facility. The cells are designed to mitigate the release of special nuclear material to the environment in the event of a detonation of high explosive within the Gravel Gertie.

Although there are some subtle differences between the cells of DAF and Pantex, their general design, geometry, and configuration are similar. The cells consist of a round room approximately 10.4 m in diameter and 5.2 m high enclosed by 0.3-m-thick concrete. Each cell has a wire-rope cantenary roof overlain with gravel. The gravel is approximately 6.9 m deep at the center of the roof and decreases toward the outer edge of the cell. The cell is connected to a corridor and subsequent rooms through an interlocking blast door. A typical configuration is shown in Fig. 1.

In the event of a accidental explosion involving significant amounts of high explosive, the roof structure is lifted by the force of the explosion, the supporting cables break, the gravel is lifted by the blast (resulting in rapid venting of the cell), and the gravel roof collapses, filling the cell. The lifting and subsequent collapse of the gravel, which acts much like a piston, is very challenging to model.

Fig. 1. Test facility layout.
Previous Approaches to the Problem

At least two attempts have been made to analyze the Gravel Gertie scenario described above. Both Nguyen and Rose and Griffith et al. published reports analyzing these scenarios for DAF and Pantex, respectively. Each analysis used the control volume computer model CONTAIN to analyze the effects of a postulated explosion in a cell. CONTAIN has features that are well suited to this type of modeling, including a control volume approach to thermodynamics, airflow among the control volumes, transport of aerosols, and heat generation and transfer. However, certain limitations are inherent in the implementation of control volume modeling of this particular scenario. Specifically, the dynamic nature of the actual volume of the cell as a result of the lifting and subsequent falling of the gravel roof (a continuous volume change) requires special modeling.

The published analyses of an explosion in a cell implemented various strategies to treat this phenomenon. In particular, energy manipulation within the cell and a constant volume pressure calculation via a secondary code have been used. In the first case, the pressure response of the cell mimicked the pressure history from an actual Gravel Gertie test. (This test is discussed below.) This was accomplished by adding gas to the cell to increase the pressure and subsequently adding a liquid energy sink to decrease pressure in the assembly cell. The other method calculated pressure response in the cell at a constant volume via a secondary code and imposed the response on the cell. Each of these methods ignores the essential fact that the volume of the cell is highly dynamic—the initial volume of the cell doubles in a few seconds and collapses to the interstitial volume of the gravel in a few more. Not only is the volume change not taken into account, extra mass and energy are added as well. These effects may affect the calculation of radioactive aerosol transport from the cell, which is the desired answer in most cases.

New Approach

A more mechanistic approach to the problem of modeling cell accidents was considered feasible. The goal was to develop a general approach to the problem of a high-energy explosion within a cell that models the thermal and airflow characteristics of such a scenario while also treating the dynamic behavior of the cell volume. If such an approach could be developed, an effective means of determining the aerosol release of cell accidents would be available.

The control volume code MELCOR (which is very similar to CONTAIN) was chosen to perform our analysis. Because MELCOR, like CONTAIN, does not support time-dependent volume changes to a control volume, a method of manipulating the volume of the cell was required to achieve the primary goal. It was postulated that the rapid addition and removal of water to and from a cell could be used to model the effects of the Gravel Gertie roof rising and falling into the cell.

A consequence of using water to alter the volume of the cell is the undesired heat transfer to the water from the hot air inside the cell following the explosion, an effect that would adversely change the pressure and temperature profiles in the cell. To treat this situation, we modified the MELCOR source code. The subroutine responsible for calculating the heat transfer from the water to the air in a volume was changed such that no heat or mass transfer was possible, effectively making the water a noninteracting material in the volume. This allowed the pool of water in the cell to act as an adiabatic piston representing the rise and fall of the gravel roof. Additional surface area would be added to the model to compensate for the lost heat-transfer area represented by the floor, now covered by the water.
Data from a 1982 full-scale test of a Gravel Gertie (the "Gravel Gertie Confinement Verification Program") was used to build a model. The cell was defined at its maximum possible volume of 943 m$^3$ (the volume at full gravel bed lift) and partially filled with water to make the air volume of the cell its initial volume of 482 m$^3$. Data from the test established the timing of the volume change in the accident. Assuming explosive detonation occurred at time zero, the gravel roof began ascending at 70 ms; the maximum gravel roof height of 5.93 m was realized at 1.3 s. The collapse of the gravel into the cell was complete at 3.2 s. In the model, the volume change within the cell was assumed to be linear with respect to time. Thus, water was added or removed from the cell at an appropriate continuous rate to simulate the volume change.

**Application**

To validate the new approach, we constructed a model to simulate the results of the 1982 test. A four-control-volume model was constructed to simulate the test facility. The model is shown in Fig. 2 without the environment volume. Separate volumes representing the cell, corridor, and environment were built. An extra control volume and flow path was required to add and remove water from the cell. However, it had no interaction with the remainder of the model other than to change the volume of the cell.

Appropriate flow paths were created between the corridor and the environment. A time-dependent energy source was added to the cell to simulate the explosion of 492 lb of high explosive as was used in the 1982 test. Heat structures were added to the model to simulate the walls, ceilings, and floors.

**Results**

The primary goal of the model was to mechanistically produce the response of the 1982 test. In particular, the pressure and temperature response of the cell and corridor in the 1982 test. Because of the direct relationship between temperature and pressure only pressure will be shown. The actual test results are shown in Figs. 3 and 4 and represent the cell and corridor pressures, respectively.

![Flow in and out of Assembly Cell](image)

**Fig. 2. Model of test facility.**
Fig. 3. Test facility pressure response in the cell.

Fig. 4. Test facility pressure response in the corridor.
The cell and corridor pressures for the model are shown in Figs. 5 and 6. A judgment on the adequacy of the approach can be made by comparing the pressure signatures of the model to the test.

The comparison indicates the following similarities.

- The peak pressures in the cell and corridor in the model are similar in character (though not in value) to the test results.
- The pressure drop back to zero gage in the cell is similar and occurs at approximately the same time as the test result.
- An under-pressure below atmospheric pressure occurring in the corridor in the test results is also shown by the model. Presumably this effect is a result of the piston-like effect of the gravel during rise.
- The slight pressurization of the corridor as the gravel falls (again because of the piston-like effect of the gravel) also is shown in the model results.

The primary differences between the calculations was in the maximum peak pressures, presumably because the test results recorded peak shock pressures and not static over-pressures.

**Conclusions**

A new approach was used to simulate the test results from the 1982 Gravel Gertie Verification Program. The approach involved slight modifications to the MELCOR code and the use of water to simulate dynamic behavior of the cell volume during an explosion. The results indicate that the approach did a very good job of mechanistically reproducing key phenomena, such as pressure response, associated with Gravel Gertie accidents. In particular, phenomena such as the corridor under-pressure just at peak gravel rise and corridor over-pressure after gravel fall were captured by the model. We judged that the model met our expectations for performing accident calculations and could be applied to other problems involving radioactive aerosol transport.

**References**

