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CONTAINMENT PERFORMANCE OF S-PRISM UNDER SEVERE BDB CONDITIONS

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ABSTRACT

S-PRISM is an advanced Fast Reactor plant design that utilizes compact modular pool-type reactors sized to enable factory fabrication and an affordable prototype test of a single Nuclear Steam Supply System (NSSS) for design certification at minimum cost and risk(1, 2, 3). Based on the success of the previous DOE sponsored Advanced Liquid Metal Reactor (ALMR) program GE has continued to develop and assess the technical viability and economic potential of an up-rated modular Fast Reactor called Super PRISM (S-PRISM).

S-PRISM retains all of the key ALMR design features(4, 5, 6) including passive reactor shutdown, passive shutdown heat removal, and passive reactor cavity cooling that were developed under an earlier DOE program.

An additional feature of S-PRISM involves the use an innovative containment system that reduces the required design basis containment pressure by a factor of two through the use of a controlled venting system. The performance of this innovative containment system is evaluated and described in this paper.

1.0 Introduction

To assess the robustness of S-PRISM's containment, severe beyond design basis sodium spray and pool fires were postulated and evaluated using the CONTAIN-LM code. This paper describes the results of these containment evaluations. A key finding was that the controlled venting system allows S-PRISM to accommodate large sodium spray and pool fires without producing peak containment pressures that prevented the use of a relatively large roomy upper containment sized to facilitate maintenance operations.

2.0 Discussion

The S-PRISM containment consists of two separate volumes that together surround the reactor system. The first containment volume is a leak tight steel vessel that surrounds the reactor vessel and is welded to the reactor closure. This vessel also serves as a guard vessel. The second containment region is a rectangular building located directly above the reactor closure. The above reactor containment volume is a low leakage pressure retaining steel lined concrete room that provides access to the components located on the top of the reactor vessel. The S-PRISM containment system is illustrated in Figure 1 provides plan and elevation views of the S-PRISM containment building.

The upper portion of the S-PRISM containment is a 10 meter tall room with a width of 20 m and a length of 22 meters. The steel lined upper containment structure is designed to limit leakage to less than 1 volume % per day at 0.35 kg\cm2 (5 psig) to mitigate postulated design basis accidents. The auxiliary service room that is located between the upper containment's is 8 meter tall, 9m wide, and 34m in length. It contains the primary Na service and cover gas cleanup systems as well the primary sodium storage tanks.

The lower portion of the containment consists of a 25 mm (one-inch) thick, 9.6 m diameter steel vessel made of 2-1/4 Cr-1Mo. The lower containment vessel has no penetrations and is designed to remain essentially leak tight. The (eight-inch) annulus between the reactor vessel and the containment vessel is sized to retain the primary sodium in the unlikely event of a reactor vessel leak such that the reactor core, the stored spent fuel, and the inlets to the intermediate heat exchangers remain covered with sodium. This ensures that the internal sodium flow path will not be interrupted and shutdown heat removal via RVACS and the IHTS (if available) will maintain safe temperatures within the core and reactor system. The annulus between the two vessels is filled with argon at a higher pressure (about 0.8 bar) than the reactor cover gas, which is at atmospheric pressure. The argon pressure is maintained at a constant level and is continuously monitored with pressure sensors, sodium ionization detectors, and sodium liquid detectors for early warning of any leak in either vessel.

A maintenance enclosure located above the upper confinement serves as a secondary containment. A stand-by gas treatment system with emergency gas treatment filters is used to maintain a negative pressure during maintenance and refueling activities in the maintenance enclosure.

Controlled venting from the containment region above reactor “A” to the service cell and if necessary, to the containment region above reactor “B” would occur as needed to limit the peak pressures generated by sever accidents. The use of multiple containment volumes and controlled venting reduces the peak containment pressure produced by large Na pool and spray fires by a factor of 2. Controlled venting will not occur unless the pressure level in a containment region exceeds the rupture disk set point.

Figure 2 shows how the upper containment volume will automatically be expanded to include the service room that is located between the two reactor containment volumes through the action of a rupture disk if the pressure in the first containment exceeds 0.07 bar (1 psig). Figure 3 illustrates how the various containment volumes have been modeled in a CONTAIN-LMR analysis model. In the CONTAIN-LMR analysis reverse buckling rupture disks have been utilized to vent the upper containment volume to the service room if the pressure exceeds one 0.07 bar (1 psig). If the pressure in the first containment and the service room exceeds 0.3 bar (4 psig), the service room volume will be vented to the second containment region by the action of the second rupture disk.

To provide defense in-depth, the upper containment structure has been designed to contain Na spray and pool fires that would occur if a reactor closure breach occurred as a result of a hypothetical core disruptive accident (HCDA).

Containment Performance

The upper containment structure has been designed to contain releases postulated to occur as a result of a hypothetical core disruptive accident (HCDA). This analysis has shown that the peak pressures and temperatures produced as a consequence of postulated Na spray and pool fires are within the containment design basis 0.33 bar (5 psig) if controlled venting to the service vault and, if necessary, to the containment above the second reactor is allowed. This reduces the peak containment pressures under very improbable design basis events by a factor of two. This makes it economically feasible to provide a relatively open and easily accessible upper containment space to facilitate refueling and maintenance operations.

Due to the severity of the primary Na spray and pool fires that have been assessed, S-PRISM is expected to meet all U.S. and Japanese the requirements. The postulated pool fire which has been analyzed with the CONTAIN-LMR code assumes that a large pool fire inside the reactor vessel burns until all the oxygen and water vapor in the upper containment is consumed. This event consumes 2,015 Kg (4,434 lb) of sodium.

Based on previous analysis, the radiological consequences are expected to meet both the Japanese and U.S. release criteria and meet the protective action guidelines (PAG) limits (<1 REM at the site boundary for 36 hours) which are far below the 10CFR100 limits.

Sodium Spray Fires

Although the reactor closure is expected to maintain its integrity under HCDA induced loads, two events have been established to demonstrate the large safety margins that have been built into the plant. The first event arbitrarily assumes that a hole in the reactor closure has been created which allows direct access of the containment atmosphere (air) to the top of the Na pool in the reactor vessel. The second event assumes that the integrity of the reactor closure is breached by the impact of the Na slug against the underside of the reactor closure and a 136 kg (300 lb) sodium spray fire is introduced into the upper containment region. Preliminary analysis of these beyond design basis events are discussed below.

Parametric sodium spray fire calculations have been performed to assess the S-PRISM containment that assumed that 300 lbm of sodium is sprayed into the upper containment. As Figure 4 shows, the pressure transient produced by a 136 kg sodium spray fire peaks at about 0.4 bar (6 psi) and diminishes to atmospheric pressure in about 8 hours. Figure 5 provides a short term (0.1 hour) view of this pressure transient that allows the reviewer to visualize the almost instantaneous rupture of the first disk (at 0.7 bar or one psi). The rise in pressure in the service room to the 0.27 bar (4 psi) level required to burst the second rupture disk and the rise in pressure in the second containment volume to a about 0.25 bar (3.7 psi) can also be seen in Figure 5. Figure 6 shows that the peak pressure would have reached 0.8 bar (12 psi) if a single containment had been utilized.

Sodium Pool Fire

Although a small breach in the reactor closure would restrict the ingress of air to the Na pool, this analysis assumed that the entire rotating plug was completely removed allowing the air and moisture within the upper containment to have unrestricted access to the sodium in the reactor vessel. The in vessel pool fire is assumed to burn until all the oxygen and water vapor in the upper containment has been consumed. A preliminary assessment of this event has been performed with the CONTAIN-LMR code. These results show how the containment pressure varies over an 8-hour period when controlled venting is used. Figure 7 provides a plot that shows how the containment pressure varies over an 8 hour period when a containment with controlled venting is used. The plot shows that the peak pressure is below 0.3 bar (5 psig) and that the pressure within the containment diminishes to below atmospheric in less than 5 hours as the containment atmosphere gives up its heat to the containment structure. Figure 8 provides a short term (0.3 hour) view of the pressure transient. In this figure the opening of the first rupture disk at 0.07 bar (1 psig) is seen to occur within the first 60 seconds and the second rupture disk is seen to open about 2 minutes after the pool fire is initiated. From 2 minutes on all three containment volumes are connected and therefor operated at the same pressure. For comparison, Figure 9 illustrates how the pressure within the first containment would vary with time if controlled venting is not available. In this case the peak containment pressure is more than twice as high.

Figures 10 plots the cumulative aerosol deposition in the two containment volumes and the service cell as a function of time. Most of the aerosol that is released during the fire is deposited in one of the three cells within the first hour and that less than 1% of the aerosol is carried out of the first containment to the service room and/or the second containment. Specifically of the 2826 kg (6,235 lb) of sodium aerosol (NaOx) produced during the pool fire only 19.5 kg (43 lb) are deposited in the service room and only 1.1 kg (2.5 lbm) are deposited in the second containment.

3.0 Summary Of Containment Performance

These, assessments have shown that the S-PRISM containment system will meet all U.S. and Japanese requirements including the accommodation of a design basis Na spray fire (100 kg) as well as a very conservative beyond design basis pool fire which consumes more than 2,015 Kg (4,434 lb) of sodium without exceeding the design basis containment pressure or the structural temperature limits associated with the steel lined upper containment structure.

The innovative use of rupture disks linking multiple containment volumes in each power block reduces the peak design basis pressure and temperature conditions in the upper containment by a factor of two. This makes it economically practical to provide a large rectangular head access space for improved maintainability. The investment risk associated with interconnecting the containment volumes is acceptable because the probability of a large pool or an HCDA induced spray fire is extremely low (less than one event in 10 million years). CONTAIN-LMR analysis has shown that the deposition from either pool or sodium spray fires in the second containment would be extremely small; on the order of 0.07% for the pool fire case and 0.8% for the 136 kg (300 pound) spray fire case.

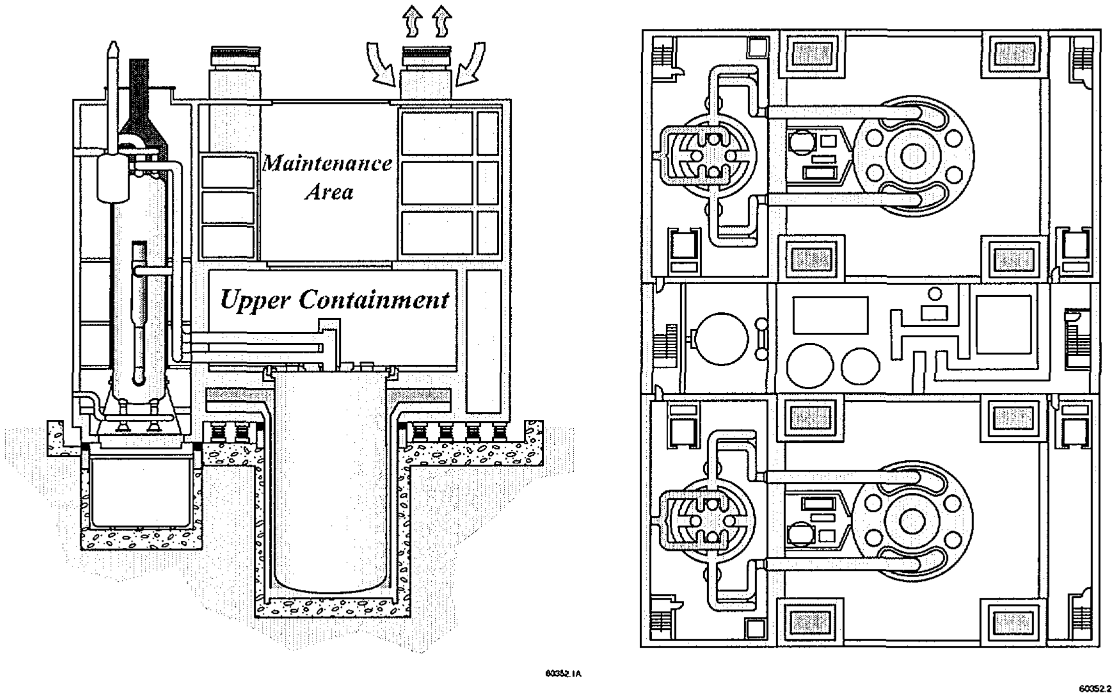

Figure 1 S-PRISM Containment Building

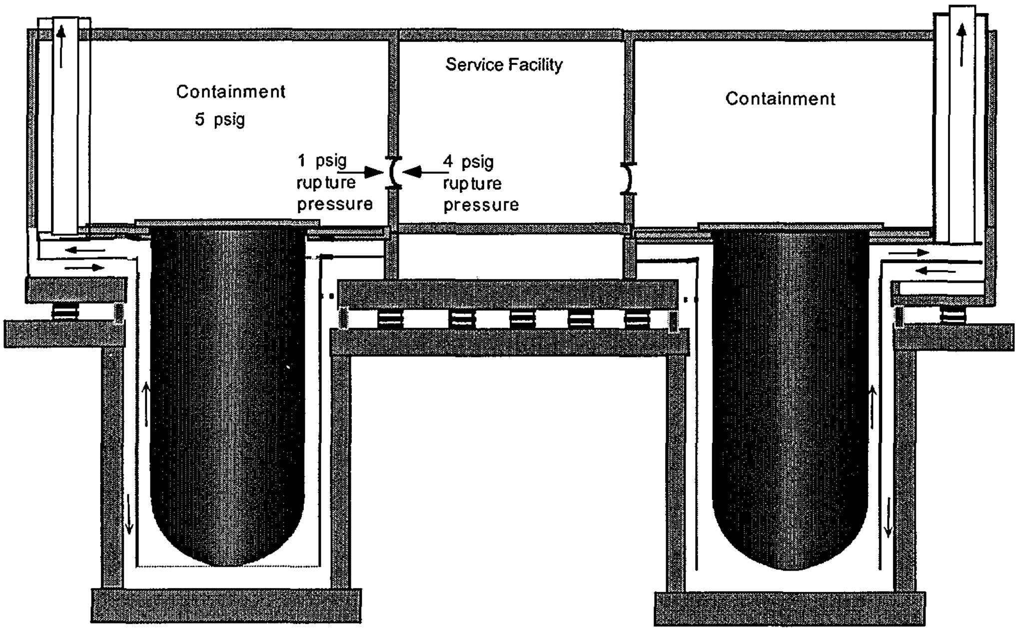

Figure 2 Vented Containment Schematic

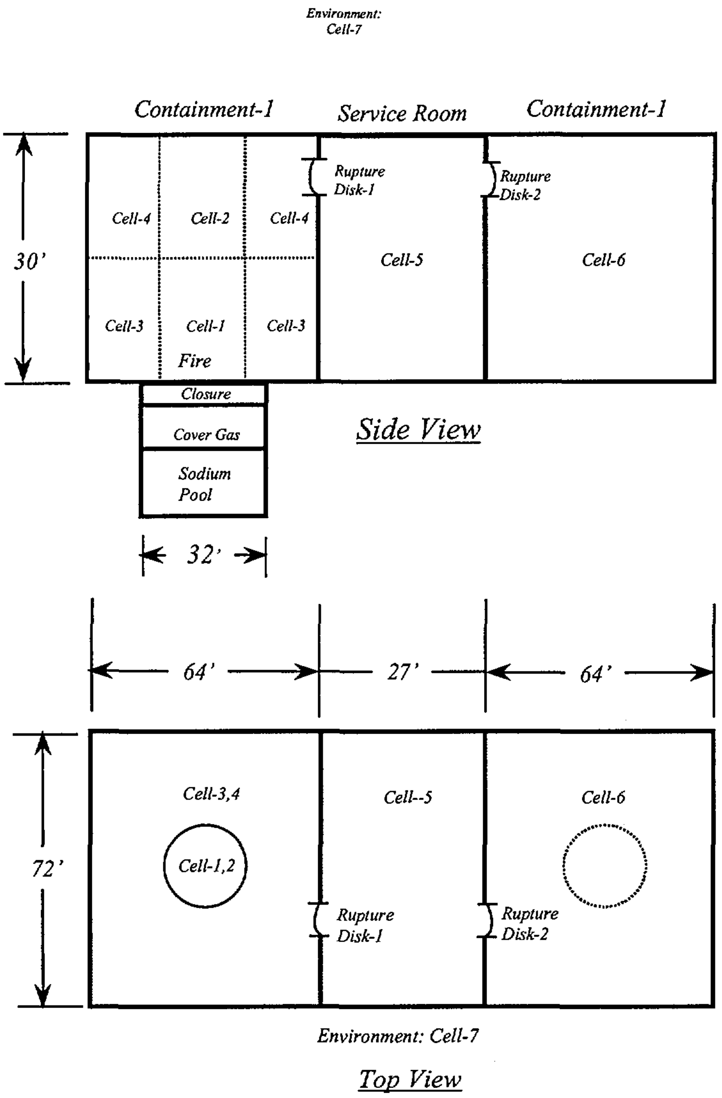

Figure 3 Calculational Cells Used In CONTAIN-LMR Spray-Fire

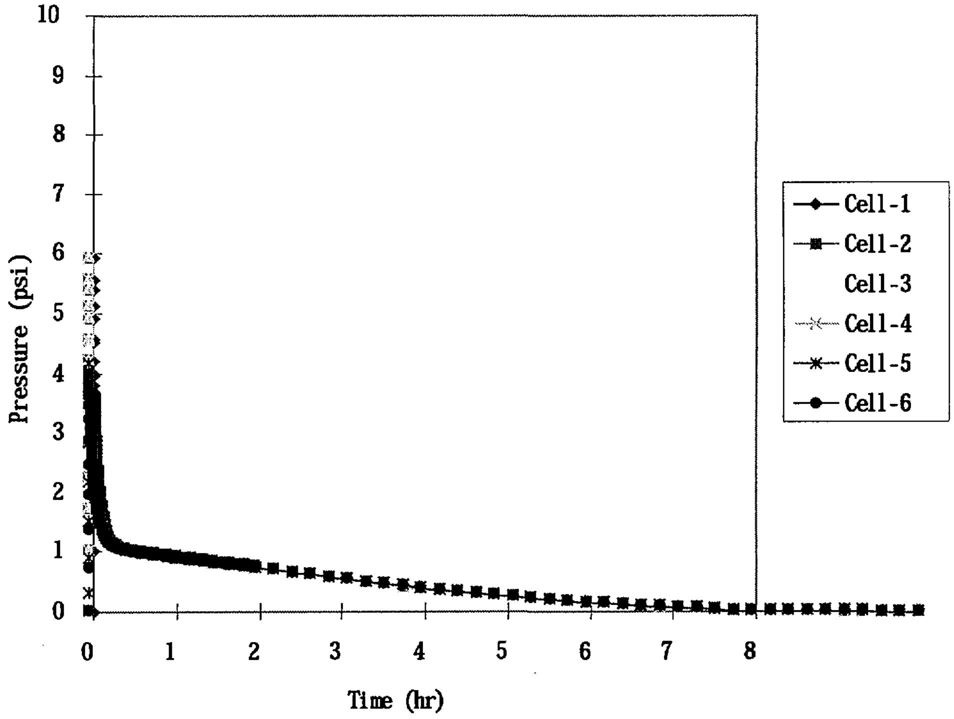

Figure 4 Pressure from Na Spray Fire (136 kg) – Vented S-PRISM CONTAINMENT

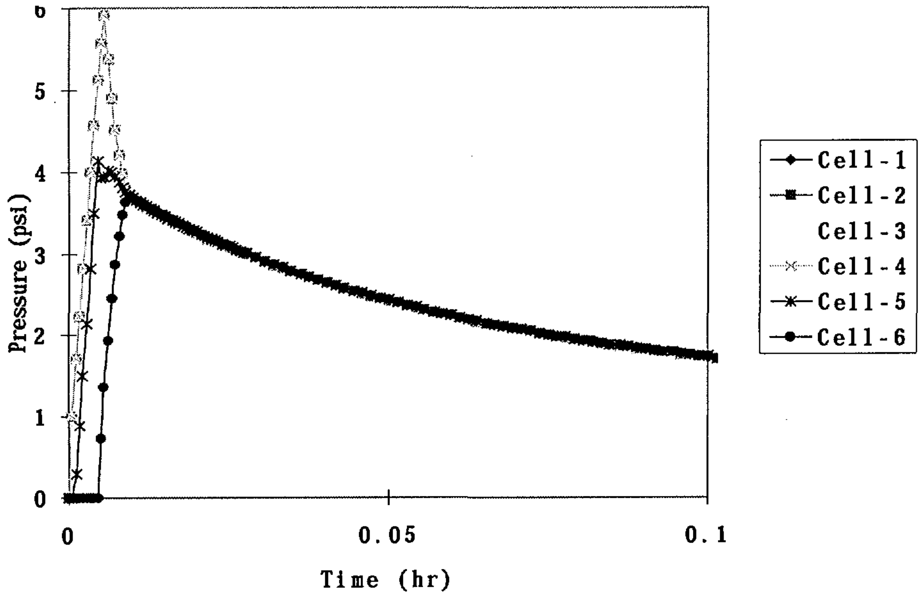

Figure 5 Short Term Pressure from Na Spray Fire (136 kg) - Vented PRISM Containment

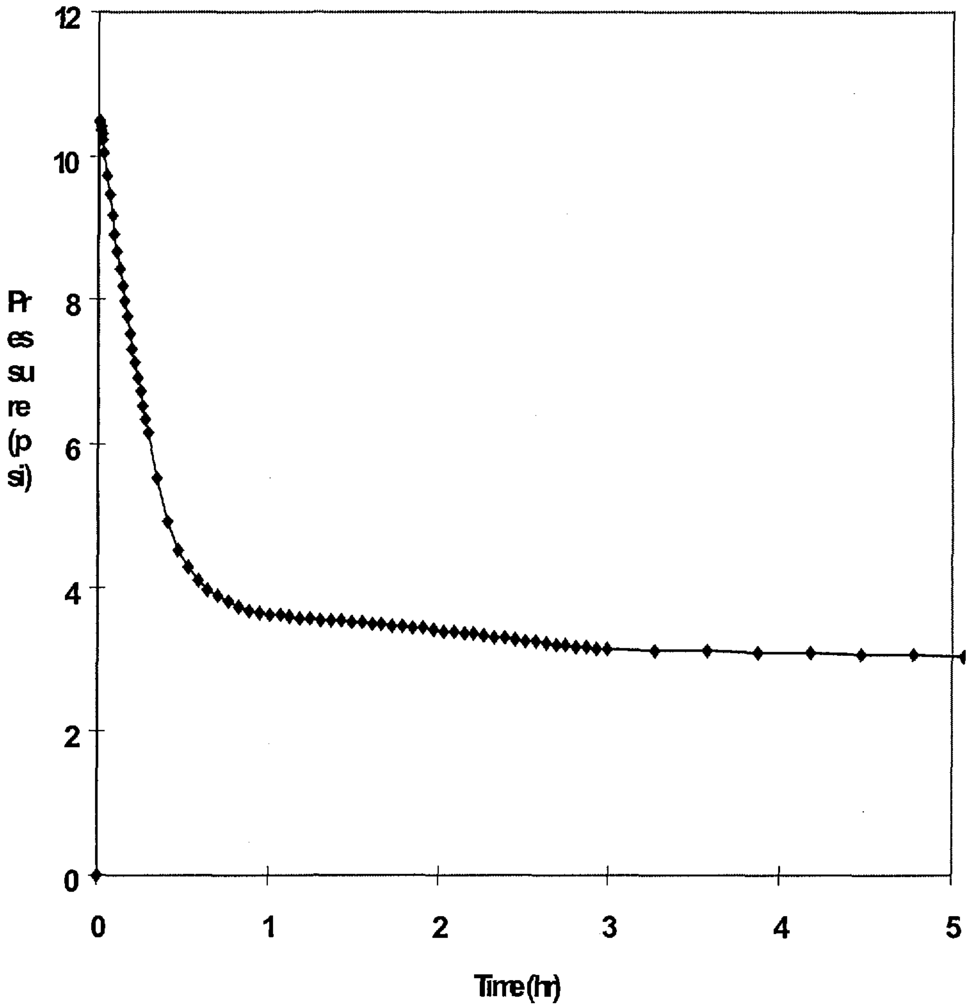

Figure 6 Pressure from Spray Fire (136 kg) - Single Containment

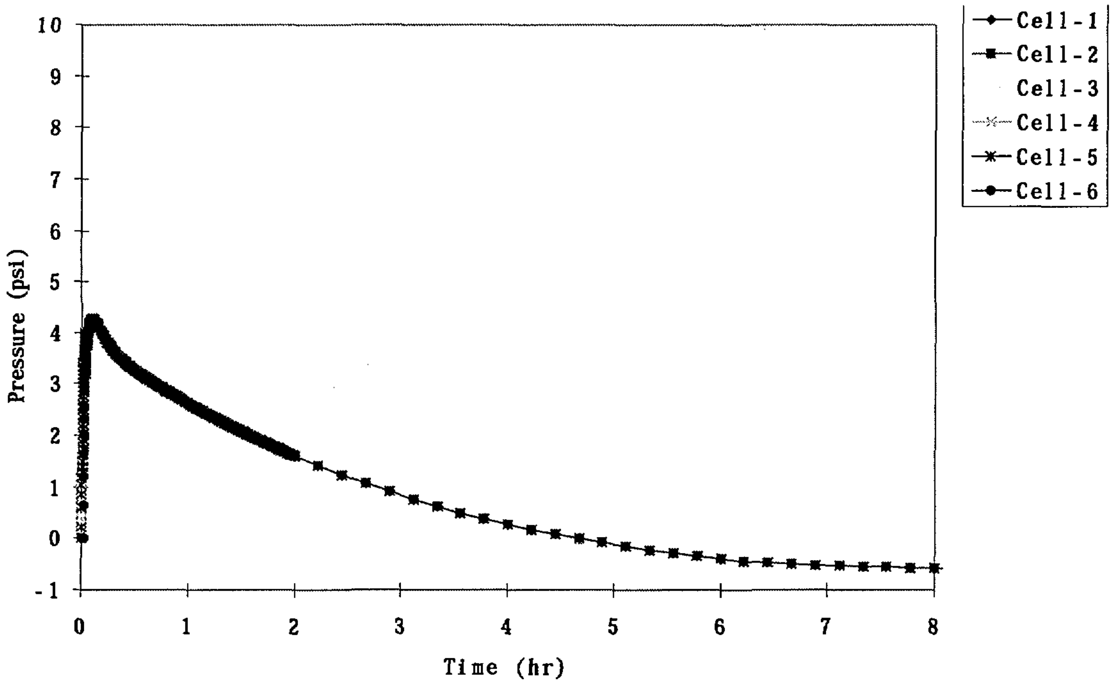

Figure 7 Pressure from Pool Fire with Vented PRISM Containment

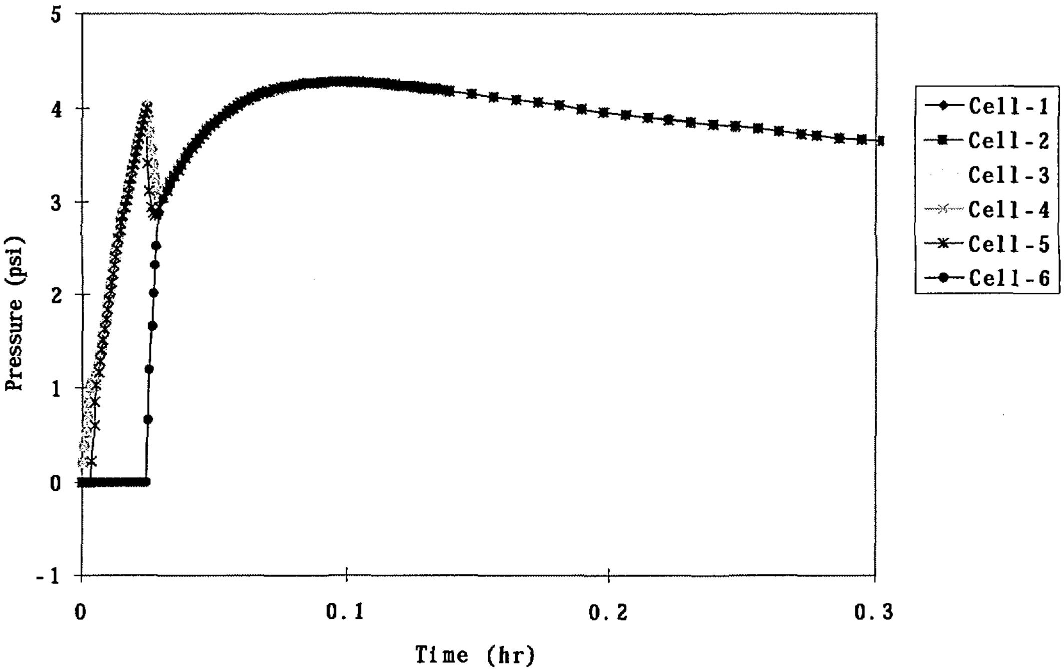

Figure 8 Short Term Pressure from Pool Fire with Vented PRISM Containment

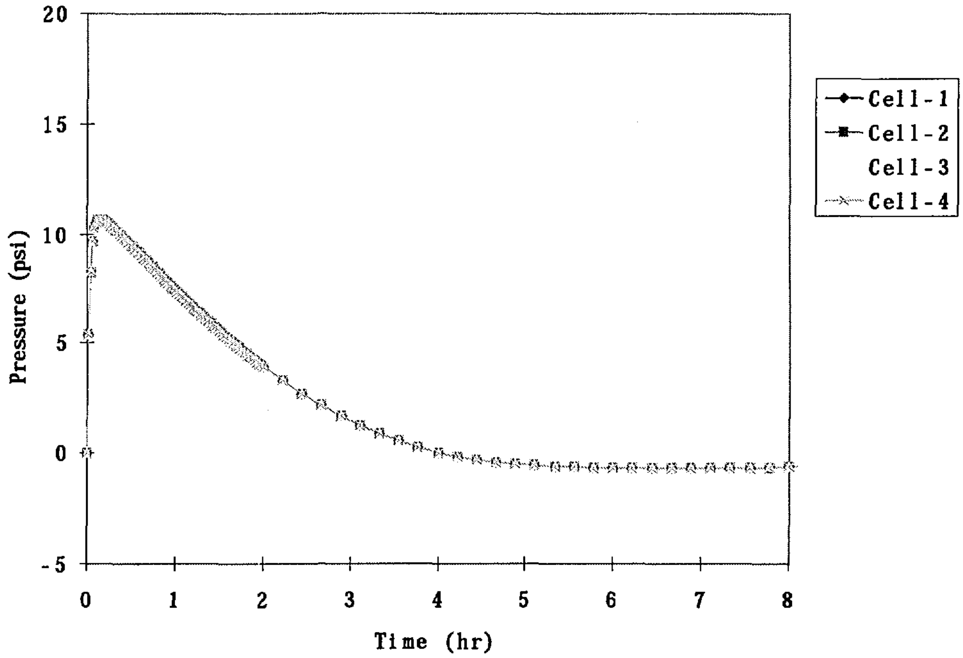

Figure 9 Containment Pressure from Pool Fire with Conventional Single Containment

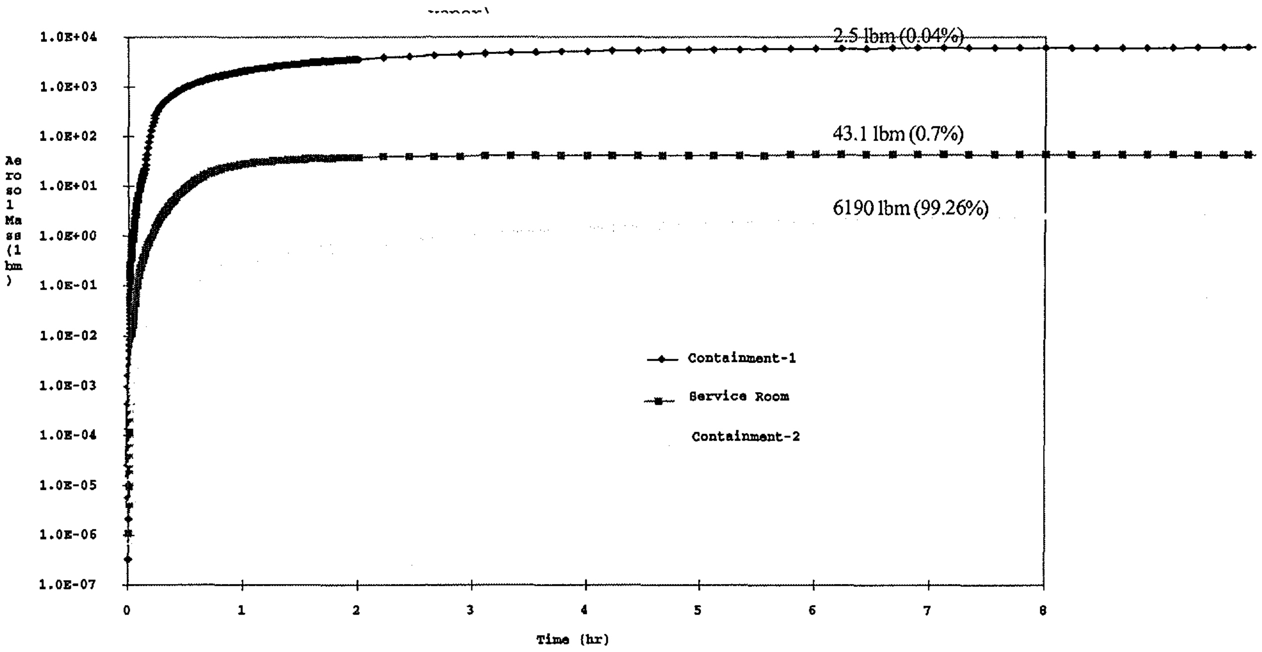

Figure 10 Pool Fire PRISM Cumulative Aerosol Deposition -(Logarithmic Scale)

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