Sodium Fire Suppression System for a Liquid Metal Fast Breeder Reactor Plant

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Abstract

The structural features of a system design to mitigate the effects of sodium fires in air-filled cells in LMFBR plants are described. The high temperatures caused by the fire under the postulated Design Basis Accident causes severe degradation of the properties of the structural steel. Thermal stresses are minimized by allowing for thermal expansion of structural elements. The design criteria and load combinations are described. The system was successfully tested with a large scale model.

1. Introduction

In a "loop" type of breeder reactor plant, the primary sodium loops transfer the heat from the reactor through intermediate heat exchangers, to non-radioactive intermediate sodium loops, which, in turn transfer the heat to the water to produce steam in the Steam Generators.

The primary sodium system is housed in the Reactor Containment Building which is arranged in reinforced concrete cells to facilitate maintenance. The cells are steel lined and are kept with an inert atmosphere to prevent fires in case of sodium leakage. The intermediate sodium loops are outside the containment in air filled cells.

Any leakage or spill of liquid sodium in such a cell can produce fire immediately upon exposure to the cell atmosphere. To mitigate the effects of a sodium fire in an air filled cell a Sodium Fire Suppression System was developed for a Liquid Metal Fast Breeder Reactor (LMFBR) Plant.

2. Description

The Sodium Fire Suppression System is a passive system, requiring no power for its operation and minimum maintenance. The system functions by collecting the liquid burning sodium into steel catch pans and by draining it by gravity into an oxygen depletion compartment where the fire is extinguished by cutting off the supply of air. (Figure 1)

The Sodium Fire Suppression system consists of the following elements:

Catch Pan

The catch pan consists of 3/8 inch carbon steel floor plates and sidewall plates continuously welded to form a leak tight container. The catch pan protects the concrete structure from exposure to liquid sodium, thus preventing sodium-concrete reactions.

The catch pan is designed as a "floating" structure allowing free thermal expansion to minimize thermal stresses. For this purpose adequate gaps are provided between the catch pan walls and the concrete walls or steel supports which could restrain the catch pan free expansion (Figure 2).

Fire Suppression Deck

The fire suppression deck acts as a barrier between the liquid sodium pool collected in the catch pan underneath and the cell atmosphere above.

It consists of standard Q deck floor panels, 4½ inch deep supported on steel framing. The deck connections to the steel framing and steel framing connections are designed to allow for thermal expansion thereby minimizing the thermal stresses.

A steel grating is provided above the deck to serve as a walkway and to provide access for maintenance. The steel grating does not have a fire suppression function.

Fire Suppression Deck Support Framing

The fire suppression deck support framing consists of wide flange beams and tee sections supported on stub columns anchored to the floor concrete. On the perimeter of the cell the beams are supported on steel brackets anchored to the concrete.

Deck Drains

The liquid sodium spills onto the top surface of the fire suppression deck and from there flows through drain pipes into the catch pan. The drains are 1½ inch diameter carbon steel pipe which extend downward to a point just above the catch pan (Figure 3) and are welded to the deck. The deck drains are spaced to form a uniform array over the cell floor area. As the liquid sodium drains into the catch pan and the drain pipes become partially filled, the effective burning surface of the resulting liquid metal pool is limited to the cross sectional area of the drain pipes. In order to limit the effective burning surface the total drain pipe cross-sectional area is specified to be approximately 0.4% of the total deck area. Burning is terminated when the pipes become plugged with combustion products and air is prevented from reaching the liquid metal pool surface.

The gap between the bottom of the drain pipe and catch pan plate is limited to 5/8".

Fire Suppression Deck Vent Pipes and Vent Lids

Vent pipes are welded to the fire suppression deck and extend above the deck (Figure 4). They are provided to vent hot gases from the region below the deck to the cell atmosphere to prevent pressure buildup below the deck.

A vent lid is provided at the top of each pipe and is seated on the vent pipe collar. Machine screws passing through oversize holes in the vent lid guide the lid and permit it to lift up to relieve any pressure buildup underneath the fire suppression deck. When the pressures above and below the deck are equalized, the lid is reseated by gravity on the collar effectively sealing off air inflow to the oxygen depleted zone below the deck.

Insulation

To protect the reinforced concrete building from excessive temperature, insulation is provided under the catch pan floor and around the perimeter of the catch pan wall.

An MgO gravel bed is placed on the concrete floor, and the catch pan rests directly on this insulation bed.

Aluminum silicate blanket type insulation (Cerablanket) is placed outside the catch pan wall and is attached to the adjacent concrete wall by means of studs welded to steel strips embedded in the concrete wall.

3. Loads, Load Combinations and Design

The load combinations are given in Table I. The Design Basis Accident (DBA) is an extremely unlikely event and has been conservatively postulated by considering the entire sodium inventory of a loop spilled into an air filled cell. The DBA temperatures in the fire suppression deck reach values of the order of 1400°F. This causes severe degradation in the steel properties which should be taken into account in the design. Temperature dependent degradation of A36 steel [1] is shown in Table II.

The location of the fire suppression deck relative to the catch pan should be based on the maximum anticipated depth of the sodium pool plus additional free board to allow for sloshing of the sodium pool under SSE conditions.

4. Confirmatory Testing

A comprehensive testing program [2] was conducted to validate the adequacy of the fire suppression system. The tests were conducted at the Rockwell International facility at Santa Susana, California. The program started with developmental testing of parameters and components and concluded with a prototypical Large Scale Sodium Fire Test (LSSFT).

The test article for the LSSFT consisted of a 31 ft by 20 ft catch pan covered with fire suppression deck in a test cell approximately 48' x 32' by 31 ft high (Figure 5). The test article was subjected to a sodium spill by spilling approximately 6000 gals of liquid sodium at 1000°F with variable discharge rates (60 gpm - 950 gpm) to simulate the slow, the medium and the fast spill, enveloping the DBA spill rates.

The LSSFT proved the adequacy of the fire suppression system and provided data for the verification of analytical techniques used in the calculation of the effects of sodium fires in air filled cells. Final design parameters such as pressures and temperatures were developed. The test article also included a pipe hanger and seismic snubber to demonstrate their integrity. Pipe hanger and snubbers were able to withstand the sodium fire environment.

5. Conclusions

A design of a system to mitigate the effects of fire caused by a sodium pipe break in an air filled cell of a LMFBR plant has been developed. It consists mainly of a steel catch pan covered by a fire suppression deck. Large scale model testing demonstrated the adequacy of the design.

References:

/1/ Steel Design Manual - U. S. Steel; ADUSS 27-3400-09, by Brokenbrogh and Johnston, January 1981

/2/ Sodium Fire Testing - Structural Evaluation of Sodium Fire Systems by Burns and Roe, Report No. DOE/CL/98004-03, August 1984

TABLE I

LOAD COMBINATIONS AND ALLOWABLE STRESS LIMITS

Combination	Loads	Allowable Stress
1	D + L + To + E	1.5 S (including To) S (excluding To)
2	D + L + To + E'	1.6 S
3	D + L + Ta + E'	1.7 $S_{(1)}$

D = Dead Load   L= Live Load including sodium load,

To = Normal operating thermal loads
Ta = Thermal effects under sodium fire
E = Operations Basis Earthquake
E' = Safe Shutdown Earthquake

S = Required elastic section strength as defined in Part 1 of the AISC Specifications.

(1) Plastic section modulus may be used to compute the required section strength "S".

TABLE II

DEGRADATION OF MATERIAL PROPERTIES AT ELEVATED TEMPERATURES FOR ASTM A36 STEEL

(from Reference 1)

Temperature (T^oF)	70	600	800	1000	1200	1400	1600
$\frac{\sigma_y @ T^oF}{\sigma_y @ 70^oF}$	1.0	0.96	0.88	0.72	0.38	0.20	0.12
$\frac{\sigma_u @ T^oF}{\sigma_u @ 70^oF}$	1.0	1.0	0.82	0.54	0.21	0.15	0.10
$\frac{E @ T^oF}{E @ 70^oF}$	1.0	0.93	0.87	0.66	0.57	0.35	0.18

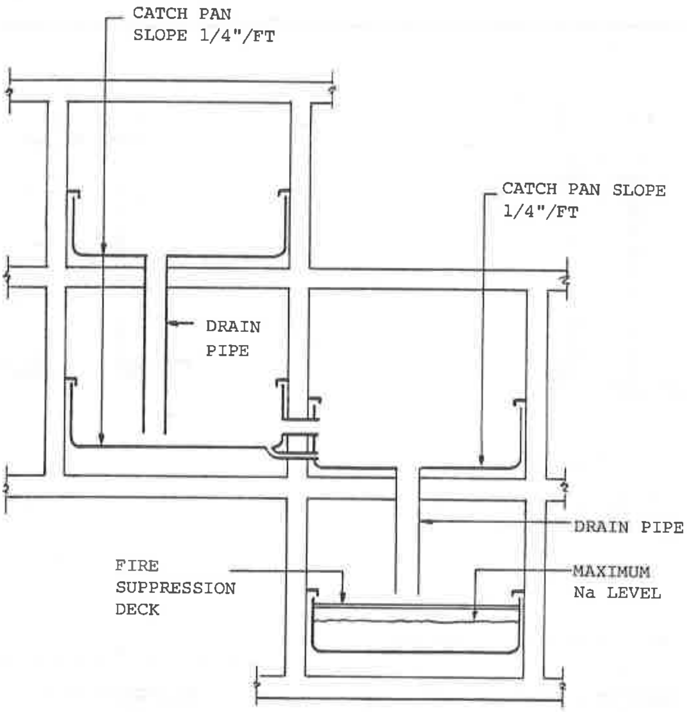


FIGURE 1 SODIUM FIRE SUPPRESSION SYSTEM CONFIGURATION

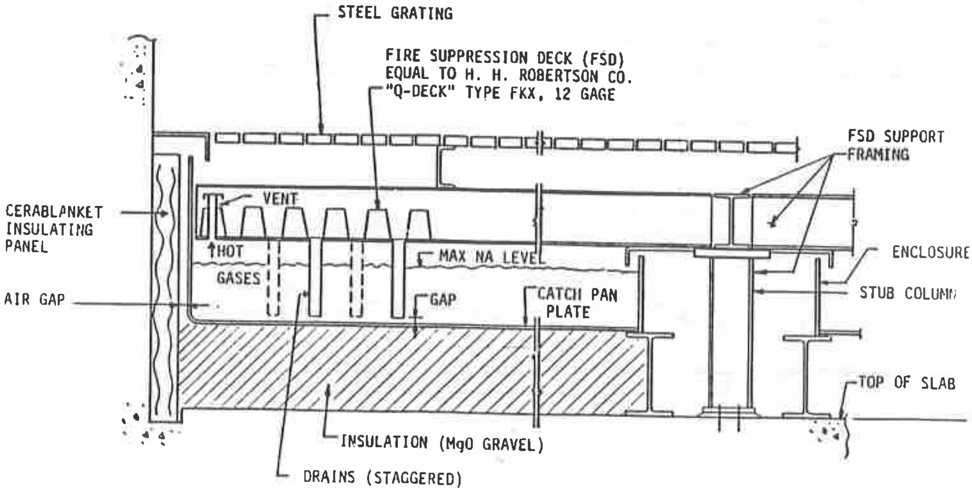


FIGURE 2 SODIUM FIRE SUPPRESSION SYSTEM ARRANGEMENT

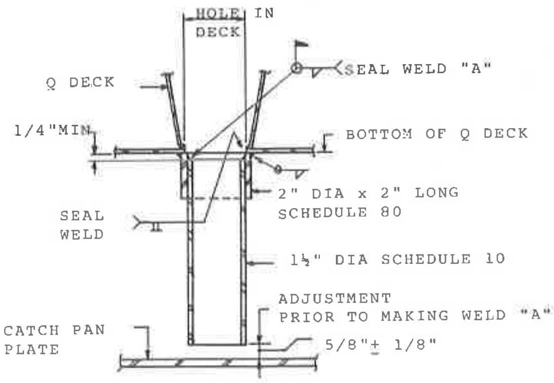


FIGURE 3

FIRE SUPPRESSION DECK DRAIN

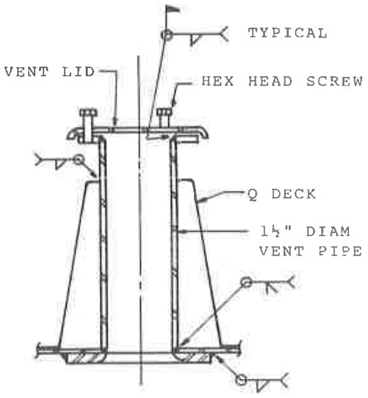
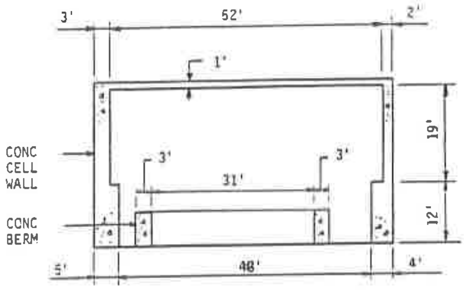
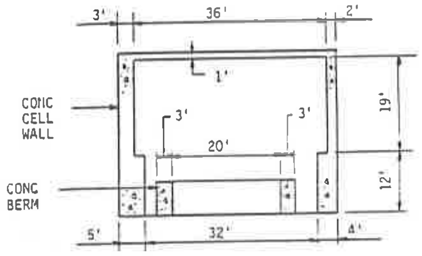


FIGURE 4

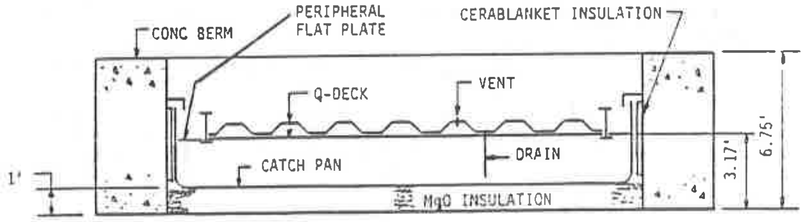
VENT PIPE AND VENT LID



EAST WEST SECTION



NORTH SOUTH SECTION



TEST ARTICLE

FIGURE 5 TEST CELL SCHEMATIC