OFFICIAL USE ONLY

SANDIA REPORT

Revision 0
Draft

Evaluation of a BWR Spent Fuel Pool Accident Response to Loss-of-Coolant Inventory Scenarios Using MELCOR 1.8.5

Draft Completed: October 2003

Prepared by
KC Wagner*
R. O. Gauntt

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0748

*Innovative Technology Solutions Corporation
6000 Uptown Boulevard, NE Suite 300
Albuquerque, NM 87110

Ex 2
entirety

G

9

OFFICIAL USE ONLY

Portions withheld -
Ex. 2 & Ex. 5

EXECUTIVE SUMMARY

In 2001, United States Nuclear Regulatory Commission (NRC) staff performed an evaluation of the potential accident risk in a spent fuel pool (SFP) at decommissioning plants [NUREG-1738]. The study was prepared to provide a technical basis for decommissioning rulemaking for permanently shutdown nuclear power plants. The study described a modeling approach of a typical decommissioning plant with design assumptions and industry commitments; the thermal-hydraulic analyses performed to evaluate spent fuel stored in the spent fuel pool at decommissioning plants; the risk assessment of spent fuel pool accidents; the consequence calculations; and the implications for decommissioning regulatory requirements. It was known that some of the assumptions in the accident progression in NUREG-1738 were necessarily conservative, especially the estimation of the fuel damage. Furthermore, the NRC desired to expand the study to include accidents in the spent fuel pools of operating power plants. Consequently, the NRC has continued spent fuel pool accident research by applying best-estimate computer codes to predict the severe accident progression following various postulated accident initiators. This report presents the results of a series of parametric calculations used to better understand the postulated accident behavior in SFPs.

The MELCOR 1.8.5 severe accident computer code [Gauntt] was used to simulate the SFP accident response. MELCOR includes fuel degradation models for BWR and PWR fuel, radiation, convection, and conduction heat transfer models, air and steam oxidation models, hydrogen burn models, two-phase thermal-hydraulic models, and fission product release and transport models. Hence, it contains the basic models to address phenomena expected during a spent fuel pool accident.

Ex. 5

Consequently, MELCOR separate effect [Wagner, 2003] and computational fluid dynamics (CFD) [Chiffelle, 2003, Ross, 2003, and Suo-Anttila, 2003] calculations were performed to develop a modeling approach for whole SFP severe accident calculations. These studies gave insights that were incorporated into the present study.

Ex. 5

Ex. 5

TABLE OF CONTENTS

Ex 5

Table of Tables

Table of Figures

Evaluation of a BWR Spent Fuel Pool Accident Response to Loss-of-Coolant Inventory Scenarios Using MELCOR 1.8.5

1. BACKGROUND

In 2001, the NRC staff performed an evaluation of the potential accident risk in a SFP at decommissioning plants in the United States [NUREG-1738]. The study was prepared to provide a technical basis for decommissioning rulemaking for permanently shutdown nuclear power plants. The study described a modeling approach of a typical decommissioning plant with design assumptions and industry commitments; the thermal-hydraulic analyses performed to evaluate spent fuel stored in the spent fuel pool at decommissioning plants; the risk assessment of spent fuel pool accidents; the consequence calculations; and the implications for decommissioning regulatory requirements. It was known that some of the assumptions in the accident progression in NUREG-1738 were necessarily conservative, especially the estimation of the fuel damage. Furthermore, the NRC desired to expand the study to include accidents in the spent fuel pools of operating power plants. Consequently, the NRC has continued spent fuel pool accident research by applying best-estimate computer codes to predict the severe accident progression following various postulated accident initiators. The scope of the present analysis is to describe the response of a reference Boiling Water Reactor (BWR) SFP to both partial and complete-loss-of-coolant inventory accidents.

Ex 5

Ex 2

The MELCOR 1.8.5 severe accident computer code [Gauntt] was used to simulate the SFP accident response. MELCOR includes fuel degradation models for BWR and PWR fuel, radiation, convection, and conduction heat transfer models, air and steam oxidation models, hydrogen burn models, two-phase thermal-hydraulic models, and fission product release and transport models. The code contains the basic models to address questions and phenomena expected during a spent fuel pool accident. included in MELCOR's fuel performance models that make application of MELCOR for SFP . Consequently, MELCOR separate effect [Wagner, 2003] and computational fluid dynamics (CFD) [Chiffelle, 2003, Ross, 2003, and Suo-Anttila, 2003] Ex 5

calculations were performed to develop a modeling approach for whole SFP severe accident calculations. These analyses helped guide the development of the whole SFP MELCOR model as well as help characterize many of the uncertainties and variability in the accident response.

Section 1.1 summarizes the two types of SFP accidents considered in the present report. They consist of a complete loss-of-coolant inventory and a partial loss-of-coolant inventory. Due to the varying phenomena, the calculated responses are discussed separately. Then Section 1.2 summarizes the structure of the report.

1.1 SFP Accident Scenarios

Ex 5

1.1.1 Complete Loss-of-Coolant Inventory Accident

Ex. 5

rate (i.e., the convection rate of the gases through the fuel), and heat transfer rate to adjacent assemblies.

An accurate analysis of the SFP response requires consideration of the aforementioned phenomena. As evidenced by the accident description, there is a large range of geometric length scales and modeling requirements. The length scales range from details of the individual assembly heat generation and flow patterns (e.g., also including multi-dimensional flow within an assembly, see [Ross, 2003]), intra-assembly heat transfer, large scale flow patterns above, below, and through the racks, and the refueling building response (e.g., ventilation, heat loss, structural failures, etc.). The relevant physics and phenomena include heat transfer (convection, conduction, and radiation), fluid flow (small scale to large scale), chemical reactions (i.e., oxidation), severe accident fuel degradation behavior, and fission product release and transport.

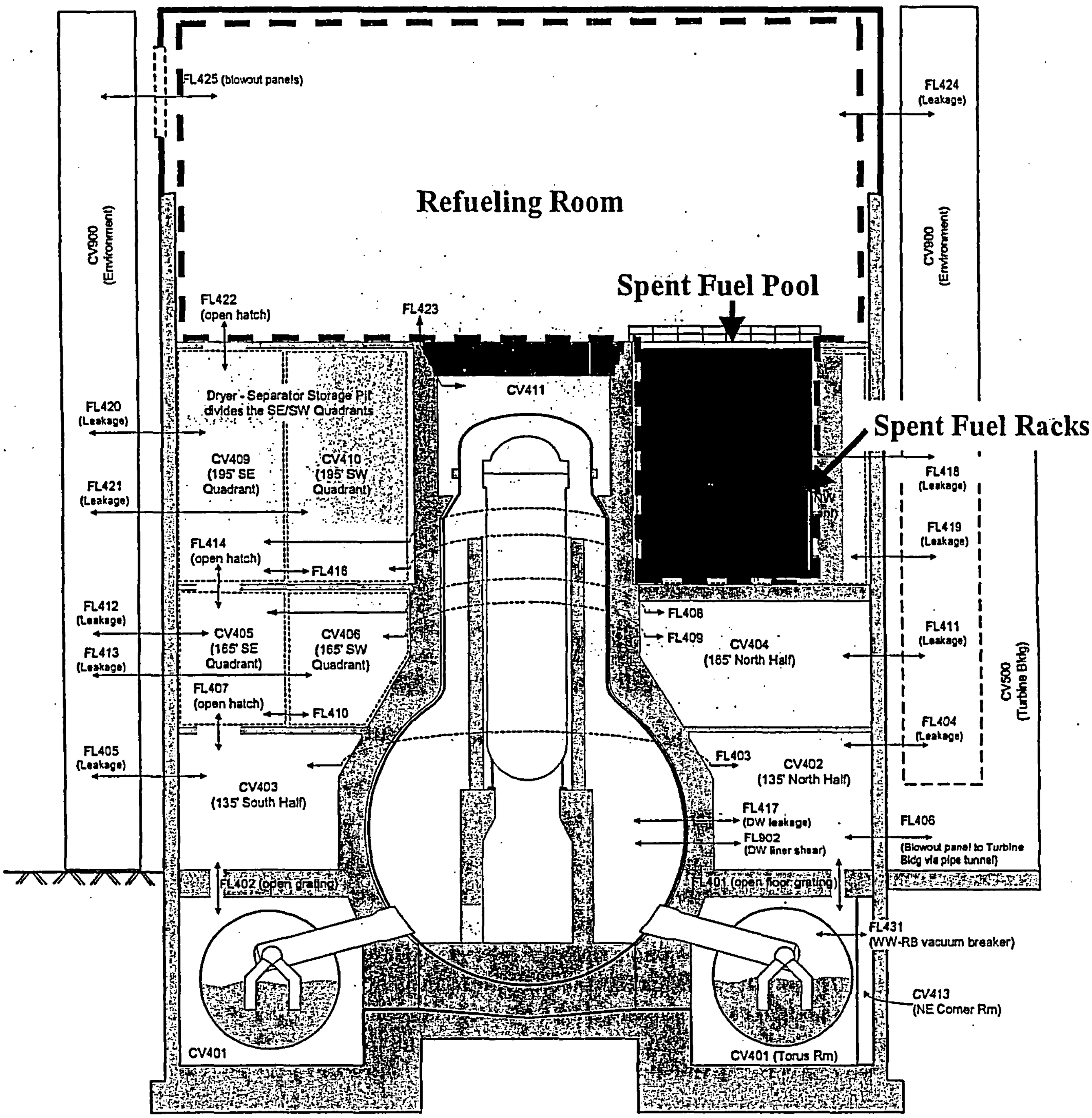

Figure 1.1.1 Reactor Building for a Boiling Water Reactor with the Spent Fuel Pool.

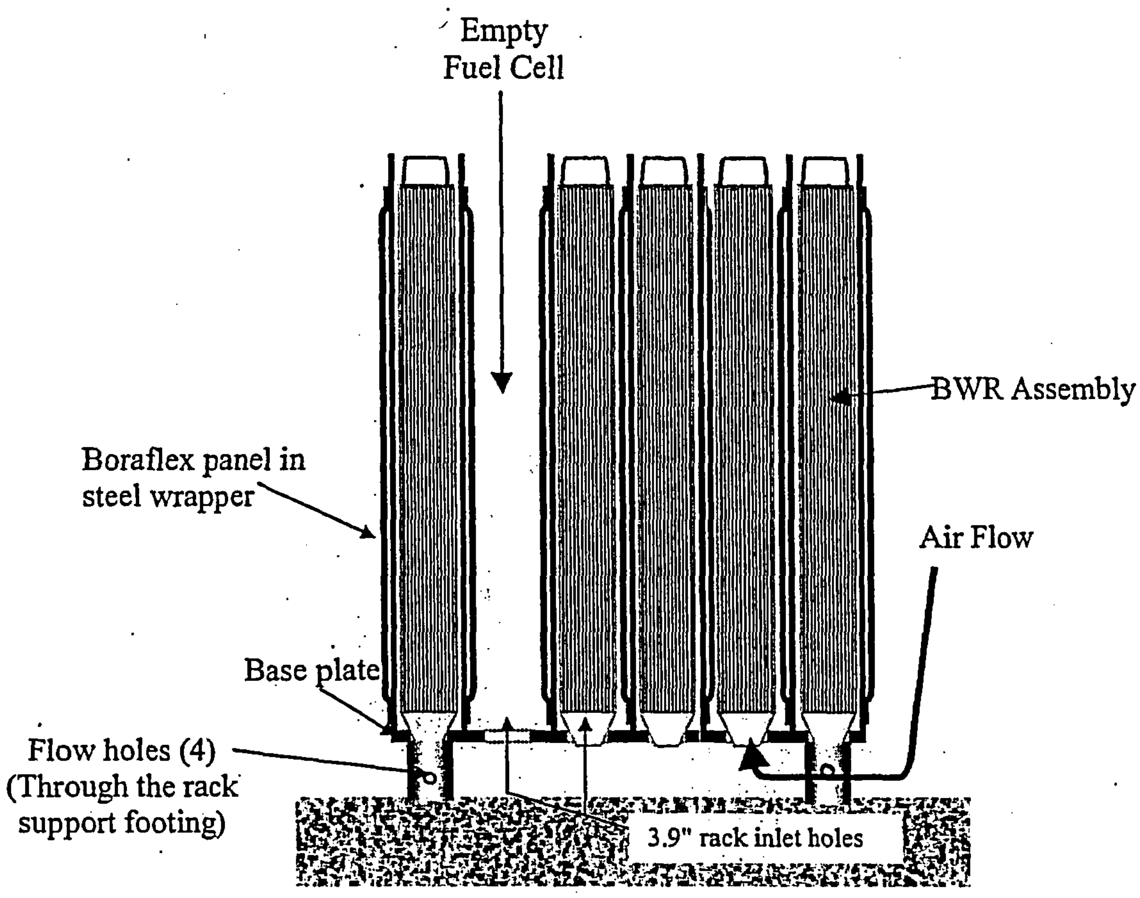

Figure 1.1.2 Spent Fuel Pool Rack with BWR Assemblies.

1.1.2 Partial Loss-of-Coolant inventory accident

In the second type of accident, the SFP is partially drained (i.e., due to partial drain or boil-off) and does not include recirculation of hot gases through the racks. Consequently, the gas in the fuel assemblies above the pool level is relatively stagnant (i.e., except for steam flow from boiling). In this condition, steam cooling and/or a level swell from the boiling will keep the fuel rods cool unless the pool level drops too far. Similar to the findings by General Electric in the 1960's, it is expected that steam cooling would be successful until the bulk pool level drops below two thirds of the fuel's height (i.e., the height of the jet pump). However, once the level drops below two thirds of the fuel height, the top of the fuel rods will heat-up and possibly degrade.

As the top of the fuel uncovers, several new phenomena occur in a partial loss-of-coolant inventory accident. First, the convective flows are much smaller than a complete loss-of-coolant inventory accident. In the complete loss-of-coolant inventory accident, there was ample air flow as the assembly heated. However, in a partial loss-of-coolant inventory accident, the fluid in the

Ex 5

1.2 Report Structure

In Section 2, a summary discussion is given on the reference BWR SFP. The modeling approach using MELCOR 1.8.5 is given in Section 3. Section 3 includes a discussion of the decay heat modeling, the thermal radial coupling, the reactor building model, the SFP nodalization, and the code model settings and sensitivity coefficients. The results of complete loss-of-coolant calculations are given in Section 4. An overall summary of their results is given in the Executive Summary. Next, the results from the partial loss-of-coolant cases are given in Section 5 . Similarly, a high-level overview is presented in the Executive Summary. Finally, the references are in Section 6.

Ex 5
Ex 5

2. SFP GEOMETRY

2.1 SFP Geometry

Ex. 2

Ex. 2

Table 2.1 Summary of SFP Attributes.

SFP Pool Characteristics	Description or Dimensions

Ex 2

Table 2.2 Spent Fuel Pool Rack Data.

SFP Rack Characteristics	Description or Dimensions

Ex 2

2.2 SFP Assembly Geometry

Ex 2

[ ] Ex 5

Table 2.3 Fuel Assembly Data.

Assembly Characteristics	Description or Dimensions

[ ] Ex 2

3. ANALYSIS METHODOLOGY

3.1 Decay Heat Calculations

The SFP contains fuel assemblies from [redacted] separate fuel offloads from the reference BWR reactor. Within a particular offload, variations in the assembly burnup and initial uranium loading are also present. The variations in these parameters lead to different levels of heat-producing decay reactions. However, as the fuel ages, the heat produced by the decay reactions decreases. [redacted] Ex. 2 Ex. 5

[redacted] Ex 5

6. REFERENCES

ANSI/ANS ANSI/ANS-5.1-1994, "Decay Heat Power in Light Water Reactors," ANS Standard, 1994.

Boyd, C., "Predictions of Spent Fuel Heatup after a Complete Loss of-Coolant Accident," NUREG-1726, July 2000.

Chiffelle, R., et al., "Analysis of Spent Fuel Pool Flow Patterns Using Computational Fluid Dynamics: Part 1 – Air Cases," Sandia National Laboratories, Informal Report, April 2003.

Collins, T. E., and Hubbard, G., "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," NUREG-1738, February, 2001.

Gauntt, R. O., et al, "MELCOR Computer Code Manuals, Reference Manual, Version 1.8.5, Vol. 2, Rev. 2", Sandia National Laboratories, NUREG/CR-6119, SAND2000-2417/1.

Ross, K. W., et al., "Analysis of Spent Fuel Pool Flow Patterns Using Computational Fluid Dynamics: Part 2 – Partial Water Cases," Sandia National Laboratories, Informal Report, April 2003.

Suo-Anttila, A, J., Wagner, K. C., Gauntt, R. O., "Analysis of Spent Fuel Pool Flow Patterns Using Computational Fluid Dynamics: Supplement - Thermal Plume Response," Sandia National Laboratories, Informal Report, July 2003.

Wagner, K. C., et al., "Evaluation of Spent Fuel Pool Accident Response to a Complete Loss-of-Coolant Inventory Using MELCOR 1.8.5," Sandia National Laboratories, Informal Report, January 2003 [2003a].

Wagner, K. C., et al., "MELCOR 1.8.5 Separate Effect Analyses of Spent Fuel Pool Assembly Accident Response," Sandia National Laboratories, Informal Report, June 2003 [2003b].

Release